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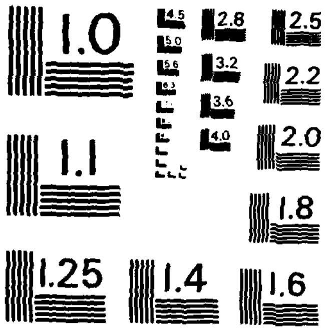
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ENHANCING INTEGRATION AND RESPONSIVENESS IN NAVAL AVIATION LOGISTICS: SPARES STOCKAGE ISSUES

John B. Abell, Christopher L. Tsai

January 1985

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Prepared for The Department of the Navy

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This Note discusses current stockage policies and computational techniques in naval aviation and argues that the use of a weapon system availability objective function coupled with multi-echelon optimization techniques could result in substantial improvements in system performance at current levels of investment. A demonstration is included that compares the estimated performance of the stockage posture resulting from an emulation of the Navy's current computational methods with that of alternative methods. The Navy's technique of minimizing the sum of holding plus shortage costs subject to a fill rate constraint is shown to be dominated by each of the alternative computational approaches. Additional research and implementation issues are also discussed.

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PREFACE

This Note reports work undertaken by Rand under the sponsorship of the Assistant Secretary of the Navy (Shipbuilding and Logistics). This work is part of a broader, continuing effort to enhance the integration and responsiveness of the naval aviation logistics system. This Note discusses alternative stockage computational techniques for aviation spares. It compares the estimated effectiveness of the resulting stockage postures with an emulation of the Navy's current techniques using the same investment levels.

Included here is a discussion of the levels of demand variability in the current system, and of the implications of that variability for flexibility and responsiveness, especially in combat.

The Note should be of interest to logistics managers and policymakers in naval aviation.

SUMMARY

This work evaluates alternative stockage computational techniques for aviation spares and estimates the levels of weapon system availability that might be achieved by the resulting stockage postures. The alternative methods are compared on an equal-cost basis with an emulation of the Navy's current approach. Although our demonstration and evaluation are quite simplistic and cannot be translated directly to the "real world," *the numerical results are sufficiently dramatic to suggest that the recommended alternative approach is worth additional research and evaluation by the Navy*. The recommended approach seems clearly superior to the current techniques used by the Navy to compute wholesale reorder levels and retail allowances for aviation repairable spares.

During the course of this research, we also examined 3M data from the Navy's aviation maintenance data collection system on several arbitrarily selected, weapon-replaceable assemblies (WRAs) on the F-14 aircraft. The data revealed levels of demand variability far beyond the levels planned for in determining allowances. This finding, however preliminary and tentative, implies the need for enhanced flexibility and responsiveness in aviation logistics as well as modified views of stockage policies and spares requirements determinations.

IMPROVING STOCKAGE POSTURES FOR AVIATION SPARES

In the course of our evaluation of alternative stockage computational methods, we developed a way to apply a multi-echelon optimization model that deals jointly with the wholesale and retail echelons to the Navy's aviation spares stockage problem. The optimization algorithm maximizes weapon system availability. The use of weapon system availability goals for management purposes has greater operational meaning than supply materiel availability or point-of-entry fill rates. The implementation of weapon system availability management in the Navy could significantly enhance the integration of requirements determination, programming, budgeting, and the day-to-day management of

the supply system, and could strengthen the cross-functional integration of supply and other functional areas.

The demonstration of alternative stockage computational methods is not entirely conclusive, but the magnitudes of several of the results suggest that the Navy might be able to achieve substantial improvements in weapon system availability with current levels of investment. The demonstration also suggests several other important observations:

- A stockage computational method based on realistic wartime scenarios will deliver better performance than one based on peacetime flying hour programs with war reserve, range, and other additives.
- The partition that exists between retail and wholesale stockage computations in the Navy seriously inhibits cost-effective solutions.
- If retail and wholesale stockage computations must be done separately, it may be important to future system improvement initiatives that the gains achievable through optimization of wholesale reorder levels are seriously constrained by retail allowances; bigger gains are achievable at the retail level but depend on a multi-echelon view.
- The use of an aircraft availability objective function coupled with a multi-echelon optimization algorithm is clearly superior to the Navy's current computational methods.
- Any stockage computational method should be used jointly with a capability assessment model that explicitly accounts for the dynamic character of combat scenarios to estimate the wartime performance of the resulting stockage postures.
- A multi-echelon optimization algorithm that maximizes pooled availability cannot be applied in a straightforward manner to the Navy's stockage computational problem, even if it accounts for heterogeneous distributions of end items, because it penalizes sites with smaller numbers of aircraft. It must also provide for separate optimization of AVCAL and OSI allowances. This will allow for provisioning each CV and NAS separately in addition to enabling availability rates to be balanced as

desired among retail sites, while still achieving most of the advantage of the multi-echelon technique.

The logic underlying the demonstration in this Note can be extended to the initial provisioning problem [11] as well as to stockage problems involving consumables. This Note also discusses some implementation issues associated with the improved technique.

ENHANCING RESPONSIVENESS IN AVIATION LOGISTICS

The computation of retail allowances is currently based on the classical assumption of a simple Poisson process. Under this assumption the variance of the demand distribution equals its mean, i.e., the variance-to-mean ratio is unity. This assumption is important to the computation of safety levels and to estimates of stockage posture performance characteristics such as fill rates, expected backorders, operational rates, and weapon system availability. It is a measure of the uncertainty of demand. The higher the variance-to-mean ratio, the less predictable the demand.

Of the 26 F-14 components selected for examination here, 19 of them had observed demand variability at least five times as great as assumed in the computation of retail allowances. Even after correction for flying hours, 19 of the 26 had at least twice the assumed variability.

The implication of variability of this magnitude is that it is very difficult to forecast demands, even in the short term. Yet the system presupposes the ability to make such forecasts, and behaves as though past demands predict future demands and peacetime demands predict wartime demands. The uncertainties in the system even in peacetime refute that supposition. Moreover, the uncertainties in peacetime will be compounded by the disruptions, resource losses, and inevitable surprises of combat. Thus it may be unwise to depend on a spares solution alone to the problem because of the substantially higher costs associated with stockage postures that try to provide a hedge against the demand variability. The need exists to examine other solutions involving more flexible resources than spares, such as maintenance and distribution/transportation.

Demand uncertainty of this magnitude implies the need for enhanced flexibility and responsiveness in the naval aviation logistics system, responsiveness which presupposes a level of integration that the Navy does not now enjoy. Thus the thrust of this work in stockage computational techniques should be viewed in the broader context of the enhanced integration needed in the system as a prerequisite of sorts to improving the system's flexibility and responsiveness. Its implications in the larger context are both for aviation supply within itself and for the interrelationships between supply and other functional areas.

But what of the implications for stockage computations of the levels of demand variability we have shown here? No matter how responsive the system can be made, the stockage computational problem never disappears. There will always be a need for spares. The question is how to formulate a reasonable set of assumptions on which to base the computational approach, including assumptions that take advantage of what we know about demand variability. If the levels of variability we have shown here are pervasive, their use in stockage computations might very well put stockage solutions that take explicit account of the variability out of reach in terms of their costs.

On the other hand, there may be a simple method for taking explicit account of demand variability in stockage computations in a way that does not make the solutions exorbitantly costly but does yield stockage postures that are sufficiently robust in the face of uncertainty. The solution to this problem is not yet clear. Additional analysis is needed to determine the extent and magnitude of the variability as well as its persistence over time. We also need to understand better the implications of the variability for stockage computations.

The cost of hedging against the levels of uncertainty that we have seen here might be more than offset by pursuing strategies that reduce item pipelines and that enhance the selective responsiveness of the system to unanticipated demands. In other words, system performance might best be enhanced by *combinations* of techniques that (a) take explicit account of uncertainty in stockage computations, (b) reduce component repair times, order-and-ship times, and retrograde times, and (c) enhance the ability of the system to respond selectively to unanticipated demands in ways that contribute best to the combat posture of the fleet. Thus the observations made here about demand variability do not necessarily mean that optimization models are inappropriate for use in stockage computations because of the difficulty in forecasting demand. They simply imply that we need to understand the character of the variability better as well as its implications for stockage computations, and that *solutions should be sought in other areas as well as in supply*.

This argument is reinforced by the fact that the uncertainties the system faces in peacetime are compounded by the uncertainties of combat. The reduction of item pipelines and an enhanced ability to respond to unanticipated demands, coupled with improved stockage computational methods, can mitigate the effects of those uncertainties.

A RESEARCH PROGRAM IN INTEGRATION AND RESPONSIVENESS

This Note also proposes a program of research and development to be undertaken by the Navy the objectives of which are to:

- Implement capability assessment techniques at key decision points throughout naval aviation, including stockage determinations, to enhance system integration.
- Understand better the implications of uncertainty to the stockage computational problem.
- Develop multi-echelon spares stockage optimization models for computing wholesale reorder levels and retail allowances that maximize weapon system availability and that are consistent with the outcomes of the research in uncertainty.
- Develop integrated data bases that bring together the data required to support such computational techniques including military essentiality data.
- Develop strategies for improving the responsiveness of depot repair and distribution/transportation, thus coupling the depot more closely to the combat force to meet unanticipated critical demands more responsively.

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We owe a special intellectual debt to Mr. I. K. Cohen of Rand, whose creative and imaginative ideas underlie the discussions in Sections I and V. We are also especially grateful to Dr. Gordon B. Crawford, whose ongoing research provided the stimulus for the analysis in Section V.

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FIGURES

TABLES

I. INTRODUCTION

The work discussed in this Note has its roots in a larger body of work on the integration of naval aviation logistics the theme of which was articulated in an earlier Rand Note [1]. In particular, the present Note focuses on the aviation supply system, especially the Navy's approach to aviation spares requirements determination, and addresses issues of integration both within the aviation supply system and across supply and other functional areas. More importantly, perhaps, the need for enhanced responsiveness and flexibility in Naval aviation logistics is implied strongly by the findings of this work. Although its primary focus is on component-related issues, it has implications for other resources.

The observations made in this Note reinforce the findings of earlier Rand work for the Navy in the Carrier Based Air Logistics (CABAL) Study [2,3], which examined the value of an aircraft availability objective function in computing spares stockage requirements for aircraft carriers; however, the earlier work did not examine the value of multi-echelon computational techniques as this work does. Rand is also involved in ongoing work, still unpublished, to understand better the implications of variability in resource demands for stockage computations and other, broader logistics system issues that we discuss at length in Section V.

At the expense of brevity, we repeat the essential theme of Ref. 1 in the discussion that follows. The reader familiar with the earlier Note is invited to continue reading on page 5, under the heading *What Follows*.

AN INTEGRATED VIEW OF NAVAL AVIATION LOGISTICS

The integration theme is conceptually straightforward, albeit complicated in implementation. The ultimate outputs of the aviation logistics system are peacetime readiness and combat sustainability. What we mean by *integration* is the quality of a system each of whose subsystems, echelons, organizations, decision processes, goals, objective functions, performance measures, and policies are mutually consistent and oriented toward the ultimate outputs of the total system. The implicit assumption in this view is that resources can thereby be balanced in a way that enables the system to achieve its ultimate goals most efficiently.

The decisionmaking, goal setting, and resource allocations of the planning, programming, budgeting, and budget execution (PPB&E) process are intended to balance the required levels of readiness and sustainability with force structure and modernization needs while meeting fiscal resource constraints. Ideally, the specification of readiness and sustainability goals would be done with full visibility of the costs of achieving them, and the execution process would allocate expenditures in ways that maximize the readiness and sustainability achievable for any specified level of investment. Moreover, again in an ideal world, the characteristics of the operational logistics system would be such that readiness and sustainability would be maximized within the fiscal resource constraints established in the PPB&E process.

In the face of the vagaries and imperfections of the real world, such an idealized view of a perfectly integrated system may seem naive, but, nevertheless, it is a useful conceptual model in understanding how to move toward a total system that will at least better achieve adequate levels of military capability at minimal levels of investment. An idealized view, when contrasted with the current system, helps identify the specific enhancements needed to the decisionmaking process in the PPB&E context as well as the specific improvements needed in the operational logistics system.

Planning, Programming, Budgeting, Execution, and Management

Figure 1 portrays a conceptual model of an idealized system and illustrates its complexities. It extends beyond the resource allocation of the PPB&E process to include the resource management of operational logistics, hence the added dimension of *management* and the term PPBE&M. The idealized system provides for feedback of management information from operational logistics to the PPB&E process to support the planning and resource allocation decisionmaking involved in establishing readiness and sustainability goals and fiscal constraints.

Planning, programming, budgeting, and management:
an integrated process

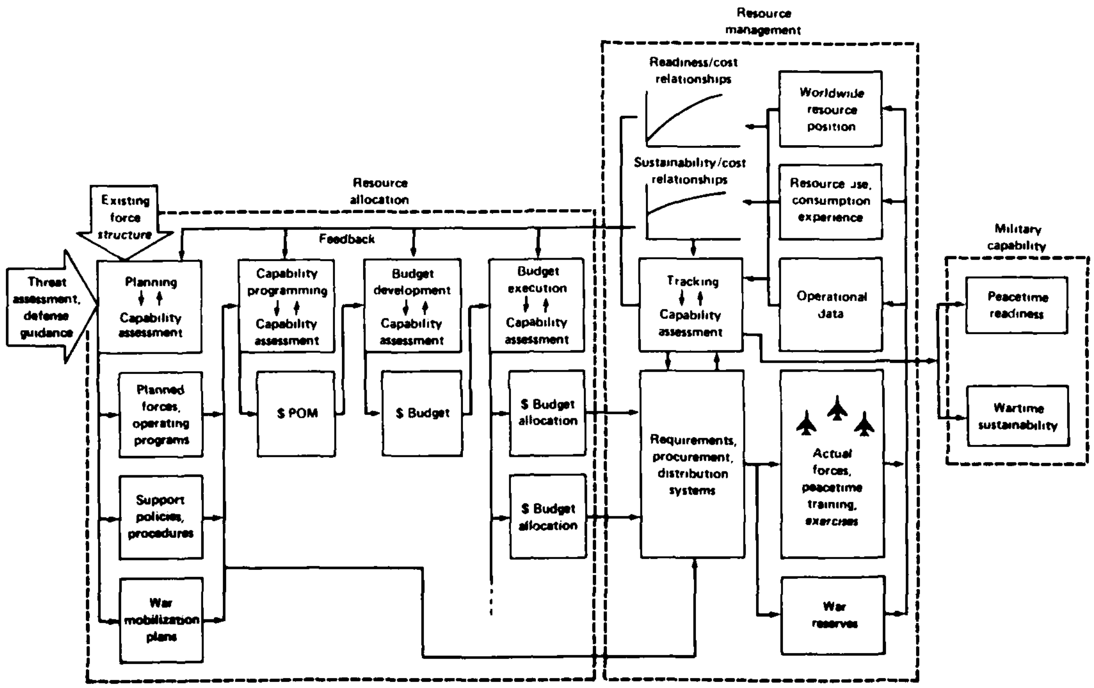

Fig. 1 — A conceptual model of the PPBE & M process

The role of planning is suggested in Figure 1 by the block at the left. The defense guidance and force structure are exogenous inputs to the process insofar as logistics support resources are concerned. The term *capability assessment* is included in each of the several major blocks representing the stages of planning, programming, budgeting and budget execution. Capability assessment is the estimation of military capability given a scenario and a particular set of support resources, policies, and logistics system characteristics. The arrows within the blocks portray the important role of capability assessment as an integral part of the decisionmaking at each stage. The concept we intend to convey is that capability assessment tools are useful not only in evaluating decision alternatives but also in formulating additional alternatives.

The decisionmaking at each stage should be consistent in terms of capability goals with the decisions made at every other stage. The use of capability assessments at each stage helps assure that consistency.

Capability goals are not represented as the product of any particular stage of the process; rather, the decisions made at each stage involve tradeoffs among resources, adjustments in investment levels, reexamination of the balance among resources, and the effects of such decisions on capability. Therefore, although capability goals may be thought of as emerging from the planning stage, they may be adjusted by subsequent decisions in later stages.

The Central Role of Requirements Systems in PPBE&M

Requirements systems have a central role in PPBE&M processes. A clear understanding of that role helps illuminate specific needs for enhanced integration, coordination, and control across all stages of the process as well as within each individual stage. Requirements determinations are first made within functional areas using computational methods that must be consistent with the execution system that will ultimately be used to allocate the fiscal resources that eventually emerge from the budgeting stage. It is essentially a "bottom-up" approach to the resource allocation process. However, it is encumbered by the fact that the original statement of requirements by the functional area consists of a single-valued requirement that is typically not determined on the basis of a computation that explicitly relates the requirement to a direct measure of military capability.

In addition, the single requirement as now computed is not based upon any commonly understood measure directly related to the operational performance of the total system; i.e., the secondary measures now in use, such as supply materiel availability rates or point-of-entry fill rates, are not directly related to measures of combat readiness or sustainability. *The most compelling argument in favor of any statement of requirements is an explication of the relationship between the recommended requirement and the level of military capability it will deliver, thus making visible what changing or underfunding it will mean to the readiness and sustainability of the combat force.*

One can raise serious questions regarding the validity of a requirements determination process in which a single requirement is computed ("the" requirement), rather than a range of alternatives each with an associated cost and capability level. Unfortunately, the Navy does not now have convenient means for exploring wide ranges of alternative levels of capability and investment without resorting in many cases to complex, costly, and time-consuming requirements computations. We explore these issues further in Section II in the context of the aviation spares requirements system.

The lack of mechanisms for assessing the capability that will be produced by specific mixes of resources, support system characteristics, and policies, given some scenario of interest, underlies many of the difficulties faced by the Navy in the PPBS process. For example, if there is no mechanism in the programming stage for relating requirements to capability, then the POM input may be viewed as largely arbitrary in the sense that the requirements it reflects are based on some intermediate (or functionally oriented) performance goals that the system sets for itself, rather than meaningful measures of military capability. Moreover, the same need exists at every stage of the process if resource allocation decisionmaking is ever going to become explicitly capability oriented.

WHAT FOLLOWS

In the remainder of this Note, we explore the application of these ideas to the Navy's aviation logistics system, especially its spares requirements determination process. In Section II we discuss the Navy's current spares requirements systems and stockage policies. In Section III we provide a simple demonstration of the value of an aircraft availability objective function coupled with a multi-echelon optimization algorithm for determining aviation spares stockage postures, and address some of the implementation problems involved with such techniques in Section IV. We return to broader, system-level considerations in Section V, where we explore the implications of uncertainty for the resource allocation process as well as operational logistics. In Section VI we suggest strategies for enhancing integration and responsiveness in the aviation logistics system.

II. SPARES STOCKAGE DETERMINATION AND STOCKAGE POLICIES IN NAVAL AVIATION

Three important characteristics of naval aviation supply inhibit the achievement of a truly integrated and responsive system. These characteristics are:

- Spares stockage computations for the wholesale and retail echelons of the system are partitioned from each other in important ways.
- Fill rates are used as objective functions, goals, and performance measures.
- Stockage policies are essentially demand-based.

THE PARTITIONED NATURE OF SPARES REQUIREMENTS DETERMINATIONS

In many ways the wholesale and retail echelons are viewed as being separate and distinct from each other. This point of view is taken in the spares requirements determination process and is implemented in a way that inhibits the achievement of the best balance of investments and resource allocations across echelons. In the wholesale requirements process, for example, no explicit consideration is given to the organizational and intermediate level pipeline or to retail allowances except as planned requirements. Similarly, retail allowances are computed without visibility of wholesale reorder levels or expected delays in resupply from the wholesale echelon.

Evidence suggests that the lack of a multi-echelon orientation in the levels computation and requirements process and, indeed, in supply system management, results in lower levels of system performance than could otherwise be achieved with current levels of investment. In Section III we try to provide some intuition about the magnitude of gains achievable from various multi-echelon approaches to spares stockage computations.

THE CURRENT SPARES STOCKAGE SYSTEM

Again at the expense of brevity, we describe the key attributes of the Navy's current spares stockage determination process to provide the motivation for the assessment of alternative approaches described in Section III. The discussion in the remainder of this section draws heavily from [1].

Wholesale Requirements and Reorder Levels

The determination of wholesale reorder levels and wholesale stockage investment levels depends upon three different computational systems. These three distinct but logically equivalent systems are: Stratification (Strat); the Leadtime Computation, Demand Forecasting, Activity Stocking Criteria and Levels Computation (Levels); and Supply Demand Review (SDR) [4-7].

Strat estimates requirements for POM and budget purposes and is a longer-range computation than is the SDR. It is run semiannually. A supporting system, the Computation and Research Evaluation System (CARES), simulates Strat and operates on a sample data base. It is designed to help decisionmakers determine desirable values of input parameters to Strat and Levels.

The Levels computation is the second principal ingredient of the system. It is run quarterly to update estimates of component characteristics such as demand rates and pipeline times. On the basis of these estimates of item characteristics, Levels computes wholesale reorder levels. The computation is designed to minimize the sum of item holding plus shortage costs. The shortage costs are associated with an SMA rate goal.

SDR, the third major component of the system, computes requirements in the short term based on the Levels outputs, i.e., for actual procurement purposes rather than for POM input or budget planning purposes. It is run weekly for consumables and monthly for repairables.

Although weapon system application and program data are used in the computation of wholesale reorder levels, the objective function is strictly item-oriented rather than weapon-system-oriented. The result is that the set of wholesale reorder levels computed by the system does not reflect weapon system complexity. A weapon system with a large number of components will therefore suffer lower levels of readiness than will weapon systems with relatively small numbers of components.

Retail Allowances

The process of retail provisioning involves the computation of stockage allowances that are reflected in Aviation Consolidated Allowance Lists (AVCALs) for aircraft carriers and in Operational Support Inventory (OSI) for naval air stations. The computation of these allowances takes no account of the wholesale stockage posture. (By *stockage posture* we mean a set of stock levels by item and location.) Yet, the expected resupply time experienced by, say, an aircraft carrier submitting a requisition to the central system depends on the total demand rate experienced by the wholesale system and on the wholesale reorder level (as well as other wholesale system characteristics). It is well known that, in a two-echelon inventory system, if the stockage posture at the lower echelon is computed in a way that explicitly accounts for the expected delay times in resupply from the higher level, it will yield higher levels of performance for specified levels of investment than will a computational method that ignores those delay times. This fact is demonstrated in Section III.

A Word About Data Bases

Strat, Levels, and CARES operate on data from various sources that reflect a large number of "component" characteristics; however, many parameters that are typically referred to as "component" characteristics are in reality performance measures of the logistics system. Such data elements as failure rate and unit cost are largely functions of the component itself; but repair times, order-and-ship times, removal rates, and BCM rates are determined largely by the structure, policies, and performance of the logistics system. In fact, even unit costs can be influenced dramatically by spares acquisition strategies. Thus data that are typically viewed as descriptive of components have much broader meaning and implications to the military programmer.

To the extent that such data elements influence resource requirements, they should be the objects of management scrutiny, not just for the sake of accuracy, but to make them a realistic model of future logistics system performance. It is insufficient to use historical observations as the sole basis for projecting future requirements, just as it is to use peacetime measures as the sole basis for forecasting wartime requirements. Moreover, management must ensure that the logistics system performs in ways that are *consistent* with that model, or that the inconsistencies and exceptions are made visible so that adjustments can be made in execution or operational management. The goal is to ensure that the military capability objectives intended in resourcing decisions are achieved in the operational environment.

OBJECTIVE FUNCTIONS, GOALS, AND PERFORMANCE MEASURES

The use of fill rates pervades the aviation supply system. Fill rates are used in establishing investment levels; they are used as goals; and they are used as measures of system performance. The fill rate measure is typical of functionally oriented measures. It is only indirectly related to readiness and sustainability. Although it is a simple measure and easily understood, it is not especially meaningful outside the supply system. More important, it is not *operationally* meaningful. The implication to readiness of a particular level of fill rate depends heavily on resupply time; thus an expected (time-weighted) backorder measure has more operational significance than fill rate. Unfortunately, the expected backorder measure is not as straightforward or as easily understood. But it, too, fails in the sense that it is only indirectly related to readiness, and it does not account for weapon system complexity as measured by the number of components per aircraft. *Weapon system availability*, on the other hand, although it does not quite convey the idea of "bombs on target," does measure very directly the end product of the logistics system: mission capable aircraft. Thus, it is a more ultimate measure of system performance than either expected backorders or fill rate. Moreover, it accounts explicitly for weapon system complexity. The specific model of weapon system availability underlying the computations and evaluations in this Note is discussed in Appendix C.

Fill rate is not actually the objective function in Levels or Strat. As pointed out previously, the computational system minimizes the sum of holding plus shortage costs by item; however, the shortage costs are exogenously specified to Levels and Strat, and fill rate is a principal focus of attention in the decisionmaking associated with the setting of those input parameters. Thus shortage costs act like surrogates for fill rate, and they can be adjusted through the use of CARES until the desired fill rate is obtained. In effect, then, fill rate really plays the role of a goal in stockage computations.

In a sense, the pervasive use of fill rates throughout the aviation supply system has some integrating value because its use as a performance measure is consistent with its use as a goal and with its use in the computational system. Unfortunately, its uniqueness to the supply system sharply diminishes its utility when requirements need to be communicated and justified to the rest of the logistics community and to others in the government. It is in this larger context that such intermediate or functionally oriented measures fail most visibly. It is also in this context that more ultimate measures, such as weapon system availability, are more persuasive. Fill rates are not expressive of weapon system readiness; weapon system availability rates are. To the extent that the relationships between fiscal resources and military readiness are important at the budget table, fill rates may fail and weapon system availability rates succeed in motivating the appropriate investment decision.

But the resource allocation arena is not the only context where measures like fill rates are dominated by more ultimate, capability-oriented measures. Clearly, if the use of a weapon system availability objective function in Levels or Strat will result in the setting of investment levels that are more appropriate, and in spares postures that deliver higher levels of readiness and sustainability for those investment levels, then it is to be preferred to the continued use of the current objective function.

A similar argument can be advanced in support of the use of weapon system availability rates as measures of system performance. They focus management attention on a more ultimate output of the system than simply its efficiency in filling requisitions. Thus we argue in favor of the use of weapon system availability rates as objective functions in spares requirements determination, in spares procurement, in component repair prioritization, and as goals and performance measures just as pervasive in character as fill rates are now.

STOCKAGE POLICIES IN NAVAL AVIATION

Stockage policies throughout the system are essentially demand based. The decision to stock or not stock an item is typically based solely on past demand. In some sense, that is an overstatement. Stockage criteria may differ by cognizance code (cog), and cogs differ by cost, expendability, etc. Less expensive consumables, for example, may have a more relaxed stockage criterion than more costly repairables. There are also special rules for insurance and numerical stockage objective (NSO) items. It is fair to say, however, that among all the characteristics of aircraft components, the use of demand rates as a basis for stockage decisions dominates all others.

The distribution of demands over weapon system components in naval aviation is concentrated over a fairly small proportion of the components. A large proportion of the line items in the system have very low or no observed demand over the time period of, say, the last two years. The important characteristic of a stockage posture that is determined on the basis of demand rate alone is its lack of range that results from the nature of the distribution of demands over line items. A demand-based stockage policy tends not to stock many of the items in the long tail of the distribution of demand rates over components; yet, *in the aggregate*, they constitute a substantial proportion of the total demand activity by sheer weight of the number of items involved.

One of the attractive features of a weapon system availability optimization model is that it stocks items on the basis of many of their characteristics rather than just demand rate. Therefore, many of the low demand items may be stocked by such a model if they are inexpensive or have long leadtimes, high BCM rates, long repair times, or high condemnation rates. The overall result is a stockage posture of considerably extended range that can be expected to deliver better performance for specified levels of investment.

In the next section, we point out some of the differences between the kind of stockage posture that results from the Navy's current computational methods and several alternative methods. Lest we lose sight of our broader perspective of an integrated system, we point out that our demonstration of alternative stockage computational methods is intended to illustrate the value of a capability-oriented objective function coupled with an integrated view of the logistics system. Thus we extend the logic of Sections I and II to a particular problem, that of computing stockage postures.

III. A SIMPLE DEMONSTRATION OF ALTERNATIVE STOCKAGE COMPUTATIONAL METHODS

In this section we describe a simple experiment in which we emulate the Navy's current spares stockage computations and compare the resulting stockage postures with stockage postures generated by alternative computational methods. The purpose of this experiment is simply to gain some intuition about the magnitude of gains in performance that might be achievable at current levels of investment by using alternative computational methods. Throughout this discussion we use the term *availability* to mean *weapon system availability*, not materiel availability. We define *availability rate* to mean the probability that an end item (in this case an aircraft) selected at random is *not* waiting for a part.

THE EXPERIMENTAL DESIGN

In past work for the Navy, Rand built computer software that emulates the Navy's computations of retail allowances for both AVCALs and OSI. In this current work we constructed additional software that emulates the Navy's computation of wholesale reorder levels. Both software packages are included in Appendix A for the interested reader. We use this software along with the actual shortage costs specified by ASO for the September 1983 Strat to compute a stockage posture. We specify certain scenario characteristics to this computation that we will describe later. The computation yields a stockage posture for the entire system consisting of aircraft carriers, naval air stations, and wholesale stockage points. The total investment level associated with this "Navy" stockage posture is then used as an investment constraint for all other computations. Thus throughout the experiment we compare *equal-cost alternatives*.

The experiment includes four other computational approaches:

- A wholesale reorder (stock) level optimization.
- An AVCAL and OSI allowance optimization.
- A multi-echelon optimization of pooled availability.
- A balanced multi-echelon optimization.

We describe each of these alternative approaches in greater detail later. What is important about them is that each uses an aircraft availability objective function, and each is, in some sense, a multi-echelon approach. (We clarify this later as well.) In addition to these four alternatives, we examine an AVCAL and OSI optimization technique that uses an aircraft availability objective function without the multi-echelon view.

THE DATA BASE

The data base for this demonstration consists only of repairable weapon-replaceable assemblies (WRAs) that apply to the F-14 aircraft. Because of data limitations, we assume that each of these items is peculiar to the F-14, i.e., we assign its total demand to the F-14. We could not infer the variance of the wholesale demand stream from available data; therefore, we assigned to each item a variance-to-mean ratio computed by the method described in Appendix B. These simplifying assumptions do not inhibit the comparison of the computational techniques; however, they do preclude translating the numerical results directly to the "real world."

The retrograde pipeline is not explicitly accounted for by the Navy's procedures. Assets are procured during the early life of a weapon system to cover the retrograde pipeline based on estimates of item characteristics and an assumption of 30 days retrograde time. Thereafter both the retrograde requirement and retrograde assets are ignored. Because of this, we excluded the retrograde pipeline from all computations since we felt that it would reflect adversely on the "Navy" computational technique. Moreover, the experiment ignores assets in the current system; it operates only with levels, i.e., wholesale reorder levels and AVCAL and OSI allowances.

The 3M system, the Navy's maintenance data collection system, was the source of item removal and BCM rates.

THE SCENARIO

The scenario used for the demonstration is only an abstraction of the Navy's actual force configuration. Thus it only approximates the dimensions of the stockage computational problem. It has characteristics that help clarify certain computational issues that are important to any eventual implementation. These issues will emerge in subsequent discussion. No attempt should be made to compare actual stock levels of components with those computed in this demonstration because of the abstractions of the scenario.

The scenario consists of two naval air stations, each with 150 aircraft, and four aircraft carriers (CVs), each with 24 aircraft. The order-and-ship time for all items is 25 days to the CVs and 10 days to the air stations. The aircraft utilization rates used were extracted from the Baseline Scenario. We explicitly assume throughout the demonstration that there is no lateral supply.

THE "NAVY" METHOD

We will describe our emulation of the Navy's stockage computational methods as the "Navy" method, implying with our use of quotation marks that our emulation may be imperfect. As we pointed out in Section II, the "Navy" method computes wholesale reorder levels without taking advantage of information about the retail level other than allowance shortages, planned requirements, and the demand stream from retail to wholesale. Similarly, it computes retail allowances without using information about the wholesale system, e.g., wholesale reorder levels, wholesale-level demand rates, or the expected wholesale delay time. Moreover, the "Navy" method minimizes the sum of holding plus shortage costs by item, rather than maximizing aircraft availability.

Using the software described in Appendix A, we emulated the Navy's computational method for the scenario described, then estimated the peacetime and wartime steady-state aircraft availability rates delivered by the resulting stockage posture. The results are shown in Table 1 and Figure 2. The availability rates in Table 1 were estimated using a

Table 1

EVALUATION OF "NAVY" STOCKAGE POSTURE

	Aircraft Availability	
	Peacetime	Wartime
Pooled	74	34
NAS	75	36
CV	72	32

model that makes no explicit assumption about cannibalization; rather, it assumes a random distribution of shortages over aircraft. The aircraft availability rate shown in Figure 2 was estimated with the Dyna-METRIC model which does not depend on steady-state assumptions [8]. It estimates aircraft availability in dynamic scenarios where activity

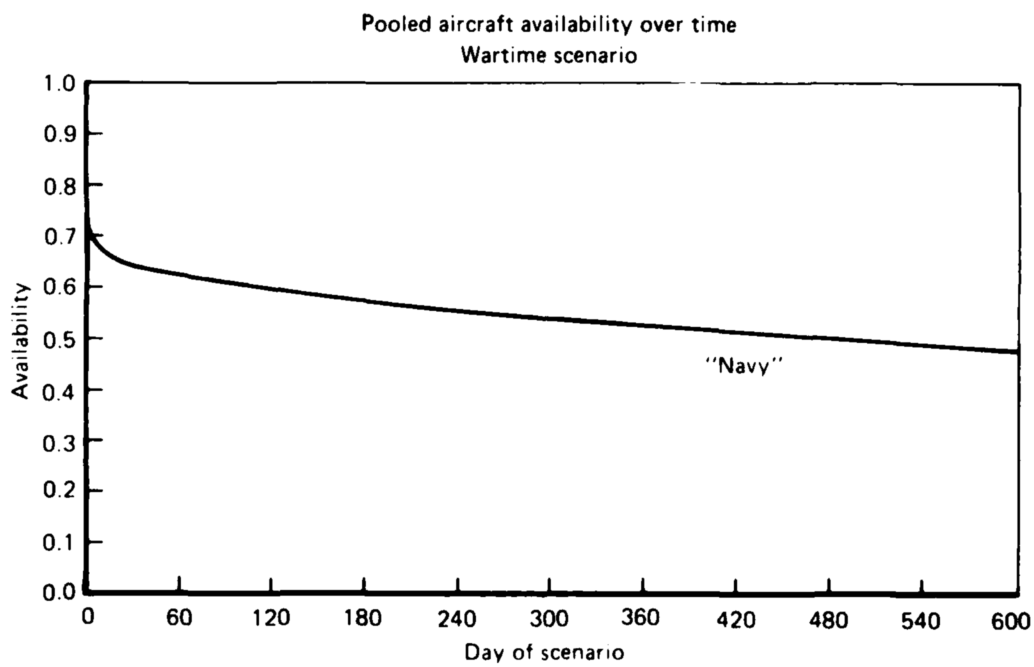

Fig. 2 — Aircraft availability over time, "Navy" stockage posture

levels may change dramatically over time. The model was applied in this case using the same assumption of randomly distributed shortages. It portrays the decline of the pooled aircraft availability rate after the wartime flying hour program begins. Clearly, it takes a long time for the availability rate to reach the steady-state value shown in Table 1. The implication of this observation is that a steady-state wartime formulation of the requirements problem may not make much sense. The dynamic character of the wartime scenario needs to be taken explicitly into account. Nevertheless, the levels of availability associated with the "Navy" stockage posture seem troublesome no matter how abstract the scenario.

It is important to point out that the estimated availability rate that might be achieved by the "Navy" stockage posture is considerably enhanced by cannibalization. The performance of this posture is improved more by cannibalization than is the performance of any of the other stockage postures evaluated in this experiment. The cost of the amount of cannibalization needed, however, is unknown but probably quite significant.

An important *caveat* about our evaluation of all of the stockage postures computed in this demonstration, but especially that of the "Navy" method, is that we assume variance-to-mean ratios according to the method described in Appendix B, the implication of which is that the "Navy" stockage posture is evaluated with higher variance-to-mean ratios than are assumed in the computation of retail allowances in the "Navy" method. For the other stockage postures, the variance-to-mean ratios used in the evaluation are the same as those assumed in the stockage posture computations. Thus one of the important differences between the "Navy" method and the alternatives examined here is the choice of variance-to-mean ratio to be assigned to the probability density function of the number of items in resupply of each type. It was not clear that this discrepancy could be avoided since the "Navy" method replicates the actual assumption made by the Navy in computing retail allowances.

OPTIMIZING WHOLESALE REORDER LEVELS ALONE

The first of the alternative computational methods optimizes wholesale reorder levels alone. The method involves the use of an aircraft availability objective function of the form described in Appendix C. Although the only decision variables involved in the optimization are the wholesale levels, the computation is done taking explicit account of retail allowances. Thus the method is a multi-echelon computation in that sense, but makes no adjustment to the retail levels. The retail allowances used are those computed using the "Navy" method. The investment level used as a constraint at each echelon in this computation is the same as that of the "Navy" method. The estimated peacetime and wartime steady-state availability rates that result from this method are shown in Table 2.

These results suggest the magnitude of gains that might be achievable from a computational method involving only the wholesale reorder levels as decision variables. The CV wartime availability is still very low.

Table 2

EVALUATION OF WHOLESALE-ONLY OPTIMIZATION

	Aircraft Availability	
	Wholesale Only	"Navy"
	Peacetime	
Pooled	79	74
NAS	80	75
CV	76	72
	Wartime	
Pooled	60	34
NAS	67	36
CV	46	32

The availability-cost curve of Figure 3 shows the flatness of the relationship between aircraft availability and investment level for the wholesale-only computation. The points shown are those associated with the "Navy" investment level.

The motivation for our original interest in this problem was the possibility of modifying ASO's requirements computations with a simple change requiring only modest cost, time, and effort that would bring a weapon system availability objective function to Strat and Levels. The relationship shown in Figure 3 led us to explore other alternatives.

OPTIMIZING RETAIL ALLOWANCES ALONE

It is clear from the example that follows that the partitioned character of the Navy's current computational technique can result in a serious imbalance in resource allocations across echelons of the system. The example consists of optimizing only retail allowances using an aircraft availability objective function and complete information about

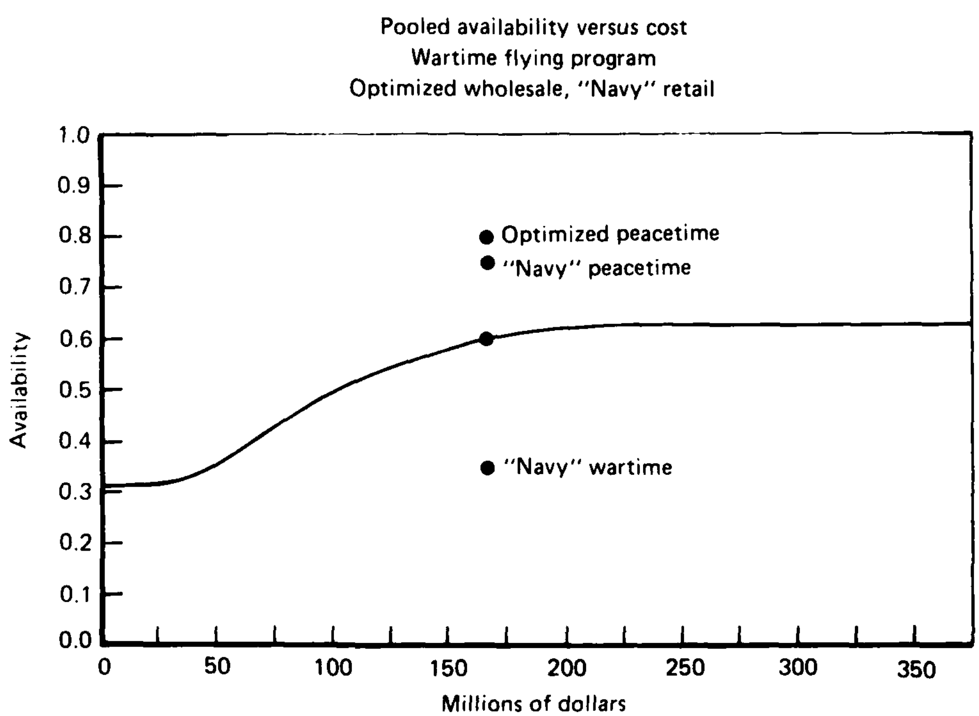

Fig. 3 — Availability/cost relationship, wholesale-only method

the wholesale stockage posture and demand stream. Thus it is another example of a multi-echelon approach in which the decision variables are at one echelon only. In this case, we use the same wholesale stockage posture and total investment level as in the "Navy" case. The estimated aircraft availability rates yielded by the resulting stockage posture are shown in Table 3.

Since this optimization was done using the wartime utilization rates, the CV peacetime availability is very high. Note, too, the substantially greater gains achievable with this method than with the wholesale-only approach, the availabilities for which have been included in Table 3 for comparative purposes. This result suggests that the partitioned character of the Navy's current computational techniques may lead to serious misallocations of resources across echelons of the system. We again point out that these "retail-only" results depend on taking explicit account of the wholesale stockage posture and demand stream in computing the retail levels.

Table 3

EVALUATION OF RETAIL-ONLY OPTIMIZATION

	Aircraft Availability		
	Retail Only	Wholesale Only	"Navy"
		Peacetime	
Pooled	88	79	74
NAS	86	80	75
CV	95	76	72
		Wartime	
Pooled	74	60	34
NAS	74	67	36
CV	74	46	32

MULTI-ECHELON OPTIMIZATION OF POOLED AVAILABILITY

In this step of the demonstration, we apply a multi-echelon optimization algorithm to the problem of optimizing all of the stock levels in the system, at both echelons and at all locations, again using an aircraft availability objective function. The algorithm allocates stock levels in a way that maximizes the pooled aircraft availability across all retail sites in the system while approximating for each item the optimal allocation of stock levels across echelons as well as across locations. The evaluation of the resulting stockage posture is shown in Table 4.

The pooled aircraft availability with this straightforward multi-echelon approach is substantially higher than with any other approach. The problem is, however, that the CV availability is significantly lower than that for the NAS. The reason for this is that the number of aircraft in the CV deckload is so much smaller than the number at the NAS. In allocating stock levels, the optimization algorithm takes best advantage of this heterogeneous distribution of aircraft in maximizing the *pooled* availability. Hence the discrepancy. (The problem of

Table 4

EVALUATION OF MULTI-ECHELON OPTIMIZATION OF POOLED AVAILABILITY

	Aircraft Availability			
	Multi-Echelon	Retail Only	Wholesale Only	"Navy"
		Peacetime		
Pooled	95	88	79	74
NAS	96	86	80	75
CV	92	95	76	72
		Wartime		
Pooled	82	74	60	34
NAS	89	74	67	36
CV	65	74	46	32

constructing an efficient optimization algorithm that will maintain equal availability across heterogeneous sites is intractable.)

The relationship between the pooled wartime availability and the total investment associated with the multi-echelon optimization of pooled availability is shown in Figure 4 along with the estimated availability delivered by the "Navy" stockage posture. Again the reader is reminded that these are steady-state availabilities based on the assumption of randomly distributed shortages among aircraft.

A BALANCED MULTI-ECHELON COMPUTATION

The undesirable imbalance associated with the multi-echelon optimization of pooled availability led to the formulation of a modified approach to the application of the multi-echelon algorithm. This approach consists of the following steps:

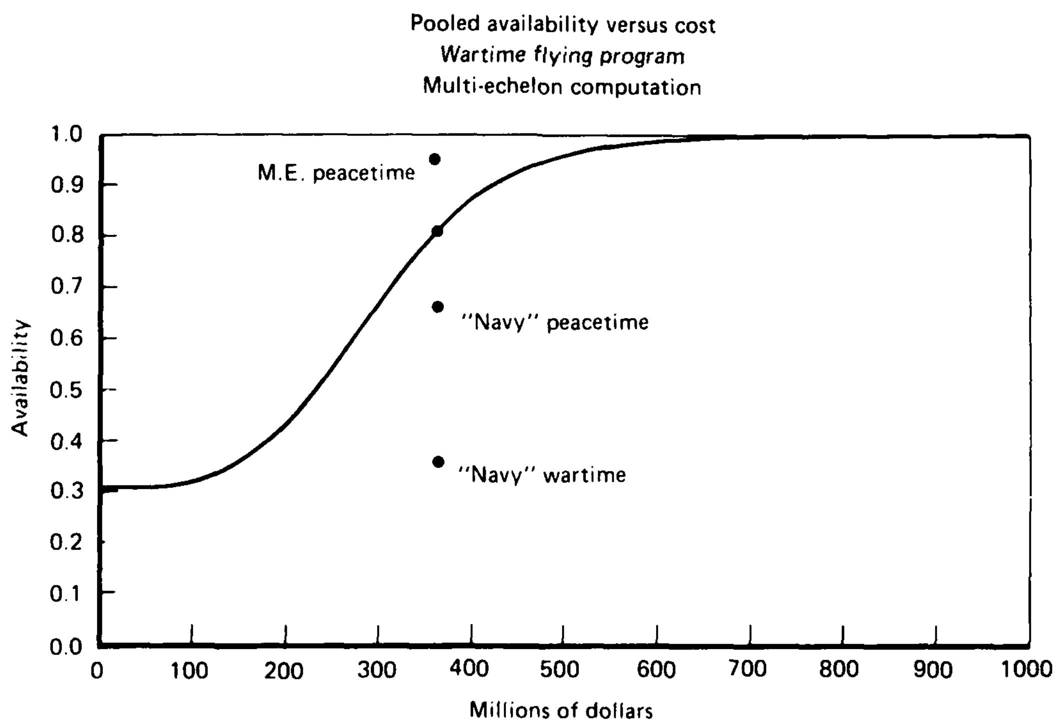

Fig. 4 — Availability/cost relationship, unconstrained multi-echelon method

- Run the straightforward multi-echelon optimization of pooled availability.
- Using the resulting availability/cost curve, select the point on the curve that is, in some sense, most desirable. For purposes of this demonstration we selected the point for which the investment level was equal to that of the "Navy" case.
- Fix the wholesale reorder levels equal to those associated with the stockage posture underlying the selected point.
- Reoptimize the AVCAL and OSI allowances using the "retail-only" approach previously described, thus enabling the CV and NAS availabilities to be established in such a way that the total investment level is still maintained but the availabilities are balanced acceptably.

For purposes of our demonstration, we chose to set the CV and NAS availability rates equal, keeping the total investment level the same as in all of the other cases. The results are shown in Table 5. The availability/cost curves are shown in Figure 5 and a Dyna-METRIC evaluation is portrayed in Figure 6 along with that of the "Navy" stockage posture for purposes of comparison.

The balanced approach has the attractive feature of allowing the decisionmaker to compensate for any heterogeneity in aircraft distribution although, obviously, some pooled availability is given up in the process.

The contrast between the balanced approach and the "retail-only" method previously described is especially interesting. In the "retail-only" method, you may recall, the wholesale stockage posture used was that of the "Navy" method, while in the balanced multi-echelon approach the wholesale stockage posture used was the one associated with the unconstrained multi-echelon computation. Thus the difference in these two approaches lies in the wholesale-level stockage posture alone. Recall, though, that both methods take full advantage of information about the wholesale level when optimizing retail allowances. Interestingly, in the balanced multi-echelon case, the wholesale stockage posture is optimized with full visibility of the retail level,

Table 5

EVALUATION OF BALANCED MULTI-ECHELON OPTIMIZATION

	Aircraft Availability				
	Balanced Mult-Ech	Multi-Echelon	Retail Only	Wholesale Only	"Navy"
			Peacetime		
Pooled	91	95	88	79	74
NAS	90	96	86	80	75
CV	96	92	95	76	72
			Wartime		
Pooled	78	82	74	60	34
NAS	78	89	74	67	36
CV	78	65	74	46	32

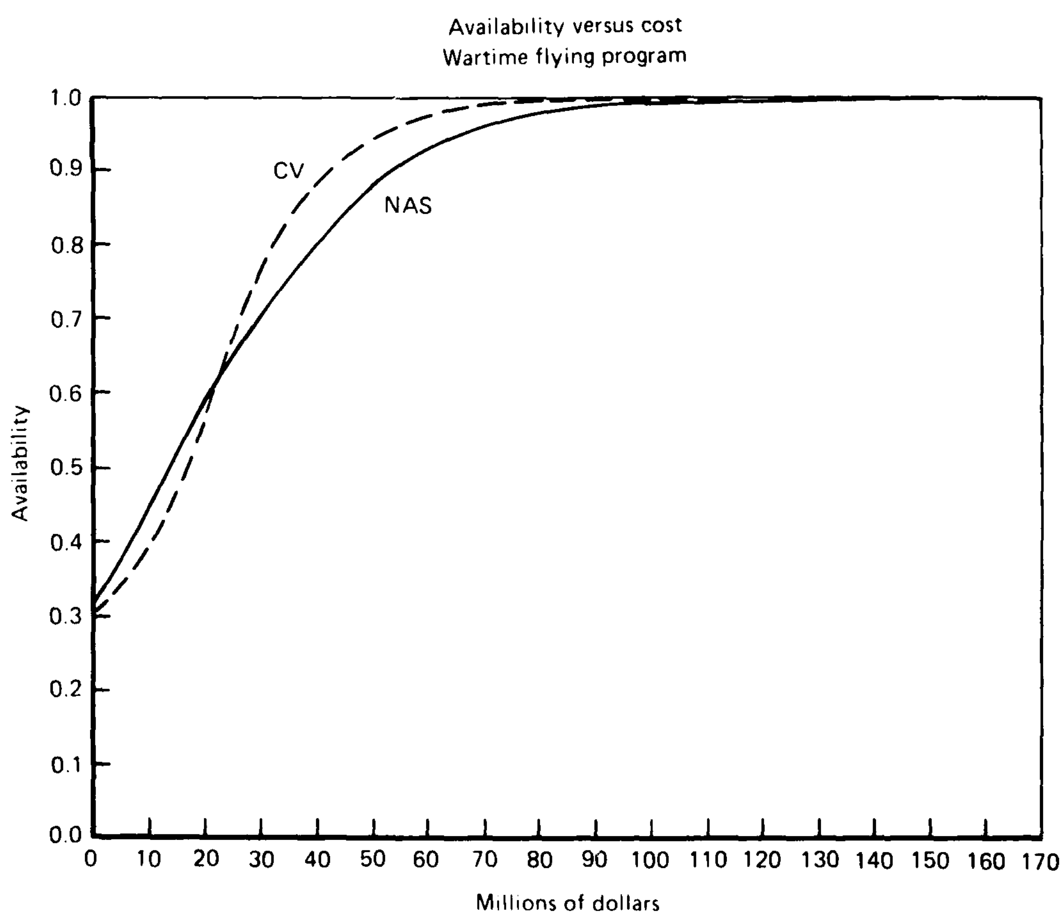

Fig. 5 — Availability/cost relationship, balanced multi-echelon method

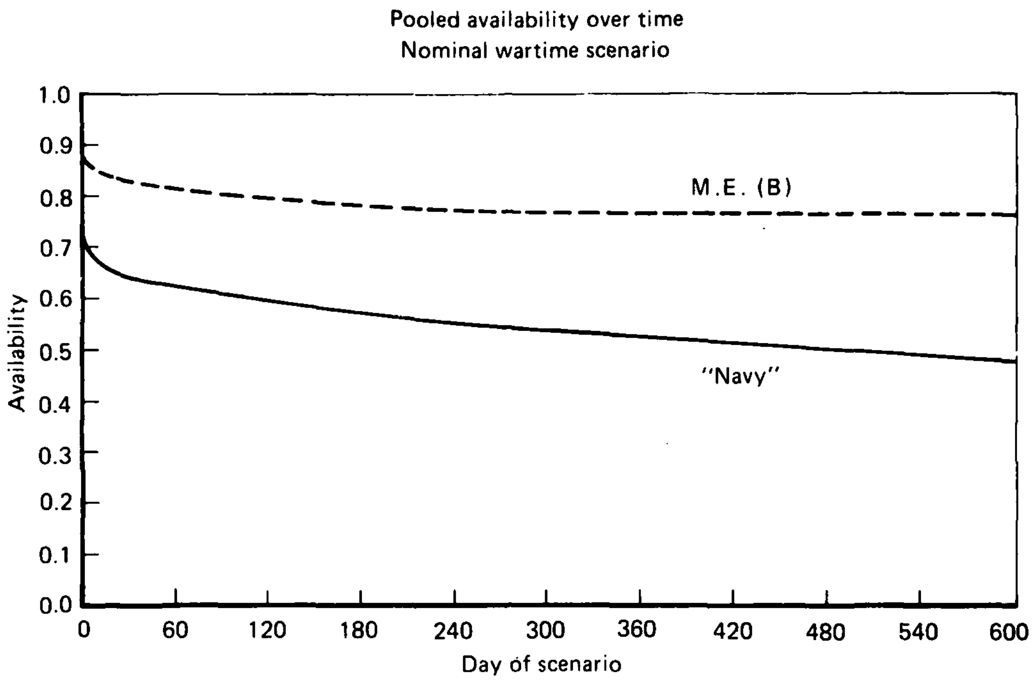

Fig. 6 — Aircraft availability over time, Navy versus balanced method

indeed of the entire system. In the "retail-only" case, on the other hand, the wholesale stockage posture is determined without using any information about retail allowances.

The remaining important research question of interest about optimizing retail allowances is how much of the overall availability gain is achieved through the use of an aircraft availability objective function and optimization algorithm, and how much through the use of complete information about the wholesale level. In other words, if we fix the wholesale stockage posture and optimize the AVCAL and OSI allowances using an aircraft availability objective function, how much can we gain *without* visibility of the wholesale level? The final steps in this experiment, which we describe in the discussion that follows, provide some intuition about this important question.

THE FUNDAMENTAL IMPORTANCE OF A MULTI-ECHELON VIEW

In the classical formulation of the multi-echelon inventory problem, the elapsed time experienced by a retail activity from the submission of a requisition to receipt of the item is the sum of two pipeline time segments: (a) the order-and-ship time and (b) the depot (wholesale) delay time [9]. The order-and-ship time is typically modeled as a constant based on actual experience. The depot delay time of an item is a mathematical expectation computed by dividing the depot expected backorders by the depot daily demand rate. Therefore, the total time that elapses from requisition to receipt depends in part on the wholesale reorder level of the item.

Obviously, the depot delay time is not the same for all items. If the wholesale level has unlimited stock of an item, the requisitioning activity will experience a total waiting time equal to the order-and-ship time. In the simplest case, if the wholesale level has no stock at all, the requisition will be delayed for the sum of the retrograde time, depot repair time, and order-and-ship time (assuming no condemnation action or procurement). The sum of expected delay time plus order-and-ship time ranges between these two extremes depending on the wholesale reorder level of the item.

The following experiment demonstrates the importance of taking explicit account of depot delay times by item when computing retail allowances.

Case 1

Consider first the case where the depot stockage posture is the same as that computed in the "Navy" case described earlier. We now compute AVCAL and OSI allowances using an aircraft availability objective function and optimization algorithm as before, but we ignore the information we have about the wholesale level and assume that all requisitions on the wholesale level are filled without delay, i.e., we assume a depot delay time of zero for all items. As before, the total investment level remains the same. The evaluation of the resulting stockage posture (made using full visibility of both echelons) is shown in Table 6.

Table 6

EVALUATION OF CASE 1

	Aircraft Availability		
	Retail Only	Case 1	"Navy"
Peacetime			
Pooled	88	89	74
NAS	86	87	75
CV	95	95	72
Wartime			
Pooled	74	47	34
NAS	74	46	36
CV	74	50	32

This is an especially important result because it suggests the magnitude of gain in aircraft availability that might be achieved by moving to the use of an aircraft availability objective function and optimization algorithm for computing retail allowances without using available information about the wholesale level. In other words, Case 1 is strictly a single-echelon computation, in the sense of both its lack of visibility of the other echelon and in the stock levels it uses as decision variables. The retail-only case described previously also optimizes only the retail stock levels as Case 1 does, but unlike Case 1, makes explicit use of information about the wholesale level, i.e., item-specific depot delay times. The retail-only case is included here for purposes of comparison because it isolates the effect of using item-specific depot delay times; that is the only difference between the two computations.

Another reason that the result of Case 1 is important is that the Navy does not account for depot delay times in its current AVCAL and OSI computations, implicitly assigning a value of zero to all depot delay times.

Cases 2 and 3

In the second case, we repeat the computation of Case 1 with the single exception that, instead of using a depot delay time of zero for all items, we specify its value to be the weighted depot delay time over all items. In Case 3, we double this value, keeping all other things the same. Now, obviously, since the computation of the weighted depot delay time depends on knowing the item-specific times, we examine this case for didactic purposes only. The question we address here is simply this: if we specify a constant as the depot delay time for all items, does the value of that constant affect the performance of the resulting stockage posture? As Table 7 shows, the answer is yes.

It is not our purpose here to search for the "optimal" value of the depot delay time when it is viewed as a constant. The basic purpose of the experiment involving these three cases is to demonstrate the importance of using knowledge of the wholesale echelon, specifically the item-specific depot delay times, in computing retail allowances.

Table 7

EVALUATION OF CASES 2 AND 3

	Aircraft Availability				
	Retail Only	Case 1 DDT = 0	Case 2 DDT = 23	Case 3 DDT = 45	"Navy"
			Peacetime		
Pooled	88	89	88	84	74
NAS	86	87	86	81	75
CV	95	95	94	91	72
			Wartime		
Pooled	74	47	56	58	34
NAS	74	46	58	60	36
CV	74	50	52	51	32

Interestingly, for the "Navy" stockage posture, depot delay times range from less than a day to more than 340 days (although only four of the 552 items in our data base had values over 200 days), with a weighted mean of 22.8 days. It seems intuitively clear that such dramatic heterogeneity should not be ignored in determining retail allowances. For the wholesale stockage posture of the balanced multi-echelon case, on the other hand, the weighted mean depot delay time is 8.6 days, with individual delay times ranging from two days to 249 days (with only one item over 200 days), and the wholesale investment level is actually somewhat less.

A COMPARISON OF THE CHARACTERISTICS OF THE "NAVY" AND BALANCED MULTI-ECHELON STOCKAGE POSTURES

A comparison of some of the numerical and performance characteristics of the stockage postures resulting from the "Navy" and the balanced multi-echelon methods is illuminating. These two stockage postures are listed item by item in Appendix E. Perusal of the list provides some additional intuition about the two approaches. There are 552 items in the data base used in this demonstration. Table 8 compares the range, depth, and fill rates of the two postures. Table 9 shows how the balanced multi-echelon technique dominates the "Navy" technique in terms of the numbers of line items with greater, equal, and less depth. The differences at the retail level are especially striking.

It is interesting to note that the fill rates for the balanced multi-echelon posture are uniformly higher than for the "Navy" posture despite the fact that the performance was optimized with respect to aircraft availability rather than fill rate. This result is consistent with other demonstrations of multi-echelon stockage optimization techniques we have seen. Relative to a fixed safety-level policy, a multi-echelon stockage optimization algorithm will give up a few of the highest cost items in favor of stocking more of a large majority of less expensive items. Thus the fill rate of the inventory system as a whole tends to be substantially improved.

Table 8

COMPARISON OF "NAVY" AND BALANCED MULTI-ECHELON STOCKAGE POSTURES

Metric	"Navy"	Balanced Multi-Echelon
Range (Line items stocked)		
Wholesale	408	449
NAS	290	522
CV	250	508
Depth (Total units stocked)		
Wholesale	9303	10914
NAS	1166	2651
CV	871	2353
Fill Rate (Peacetime)		
Wholesale	0.922	0.939
NAS	0.879	0.902
CV	0.933	0.988
Fill Rate (Wartime)		
Wholesale	0.564	0.591
NAS	0.722	0.818
CV	0.837	0.933

The experienced Navy reader will have noted that the fill rates shown for the "Navy" case in peacetime are considerably higher than those actually observed in the fleet. There are probably several reasons for this imperfect emulation on our part. The difference at the wholesale level may be due largely to the fact that the "Navy" stockage posture includes all authorized war reserve stocks. At the retail level, the difference is less obvious. It may simply be due to the assumption on our part that the total "requirement" is fully funded up to the level of the allowances computed. As mentioned previously, the computation was done using the shortage costs shown in Appendix D.

A Final Word on the Demonstration

In Section II we discussed the Navy's widespread use of demand-based stockage policies and their effects on range, cost, and performance. The differences in the two stockage postures discussed above suggest how a coherent, system-level view of the stockage problem might affect the cost and performance characteristics of the inventory. With the use of an aircraft availability objective function and a multi-echelon optimization model sensibly applied, the problem of demand criteria disappears. One need not specify range additives, war reserve stocks, numerical stockage objectives, or other "band aids" to otherwise inadequate demand-based policies. (We do not mean that there is no need for additives outside the computation.) With the appropriate formulation, the optimization algorithm can take explicit account of weapon system complexity, item commonality, levels of indenture, military essentiality, and other item and system characteristics in computing stock levels. All of these capabilities are within the state of the art of modern multi-echelon inventory theory [10].

Despite the simplicity of this demonstration, it illustrates the contrasting attributes of the Navy's current stockage computational techniques and several alternatives, the examination of each of which has some instructive value. However, except for the graphs of time-related availability in Figures 2 and 6, it may fail to convey the vital need to take account of scenario dynamics in evaluating the performance of stockage postures and setting availability goals and investment levels. This kind of evaluation is also within the state of the art. The Dyna-METRIC model and other models have the capability to estimate the performance of a stockage posture over time in dynamic combat scenarios. It is clear that such evaluations *need to be performed routinely* because they bring a wartime focus to the stockage problem and assist decisionmakers in goal setting. More importantly, such capability assessment tools help clarify the implications for military capability of alternative investment levels. This is the kind of

Table 9

COMPARISON OF LEVELS BY LINE ITEM

Wholesale Levels by Line Item	
"Navy" level greater	96
Levels equal	192
"Navy" level less	264
Total line items	552
NAS Allowances by Line Item	
"Navy" level greater	21
Levels equal	57
"Navy" level less	474
Total line items	552
AVCAL Allowances by Line Item	
"Navy" level greater	32
Levels equal	15
"Navy" level less	505
Total line items	552

integrating mechanism for which we specified the need in Section I.

Lest we convey the impression that implementation of these ideas is straightforward or that they can safely be assumed to be capable of delivering dramatic gains in performance with certainty, we hasten to add that there are some important problems still unsolved that may significantly influence the efficacy of these techniques. We discuss these problems in Sections IV and V.

CONCLUSIONS

The differences pointed out in Tables 8 and 9 are large--dramatic in fact--given that they represent equal-cost alternatives. We wish to reemphasize our earlier *caveat* about not translating the results of this simple demonstration directly to the "real world." Nevertheless, the magnitudes of several of the results suggest that the Navy might be able to achieve substantial improvements in weapon system availability with current levels of investment. The demonstration also suggests several other important observations:

- A stockage computational method based on realistic wartime scenarios will deliver better performance than one based on peacetime flying hour programs with war reserve, range, and other additives.
- The partition that exists between retail and wholesale stockage computations in the Navy seriously inhibits cost-effective solutions.
- If retail and wholesale stockage computations must be done separately, it may be important to future system improvement initiatives that the gains achievable through optimization of wholesale reorder levels are seriously constrained by retail allowances; bigger gains are achievable at the retail level but depend on a multi-echelon view.
- The use of an aircraft availability objective function coupled with a multi-echelon optimization algorithm is clearly superior to the Navy's current computational methods.
- Any stockage computational method should be used jointly with a capability assessment model that explicitly accounts for the dynamic character of wartime scenarios to estimate the wartime performance of the resulting stockage posture.[1]

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[1] Dyna-METRIC, the model used in the evaluations portrayed in Figures 2 and 6, is especially useful in evaluating stockage posture performance in combat scenarios in which activity levels and other scenario characteristics change over time. It is described in [8].

- The use of an optimization algorithm that computes an availability/cost relationship is much more useful than one that depends on specification of a Lagrangian multiplier because the latter type yields only one solution for each value of the multiplier and inhibits the allocation of resources across weapon systems.[2]
- A multi-echelon optimization algorithm that maximizes pooled availability cannot be applied in a straightforward manner to the Navy's stockage computational problem, even if it accounts for heterogeneous distributions of end items, because it penalizes sites with smaller numbers of aircraft. It must also provide for separate optimization of AVCAL and OSI allowances. This will allow for provisioning each CV and NAS separately in addition to enabling availability rates to be balanced as desired among retail sites, while still achieving most of the advantage of the multi-echelon technique.

The logic underlying this demonstration can be extended to the initial provisioning problem [11] as well as to stockage problems involving consumables.

In the sections that follow, we discuss several of the issues involved in moving toward the improved computational methods discussed here. Several are of a technical nature and seem quite tractable; unfortunately, the technical issues seem overshadowed by the levels of uncertainty in resource demands that we have observed in the current system. This uncertainty has implications for stockage computational techniques that must be accounted for.

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[2] Such an algorithm is described in [10].

IV. IMPLEMENTATION ISSUES

The Naval Supply Systems Command is in the midst of an important initiative involving modernization of its electronic data processing systems and, eventually, enhancements to the data bases and management information and computational systems they support. These initiatives, called *resolicitation* and *resystemization*, respectively, provide a unique opportunity for change. Perhaps the Navy could move toward implementation in the resystemization time frame of improved stockage computational methods although, admittedly, such a goal is ambitious. In this section, we discuss some of the technical issues that need to be resolved before implementation of improved stockage computational methods.

METHODOLOGICAL ISSUES

The specific details and configuration of the computational software that is in some sense "best" for naval aviation stockage computations is still a matter of uncertainty. Our experience and intuition suggest that, in general, it should have the features discussed in Section III. However, several design considerations have not been explicitly discussed. Among these considerations are those involving cannibalization, military essentiality, the inclusion of consumables (i.e., the modeling of (S,s) reorder policies), and the forecasting problem.

Cannibalization

The dimensions and performance characteristics of the stockage posture that emerges from a particular stockage computational technique depend heavily on the assumption about cannibalization that underlies the computation. Stockage postures that are based on the assumption of perfect consolidation of shortages tend to lack range, and their relatively higher estimates of performance *depend* on cannibalization. Obviously, though, not all aircraft components can be cannibalized. Thus the choice to be made as a matter of policy seems to be between the random shortages assumption and a cannibalization assumption coupled with a data base that reflects the likelihood that a component can be cannibalized successfully and, perhaps, the estimated cost of doing so. In other words, a cannibalization assumption seems too optimistic without taking account of the fact that some components cannot or should not be cannibalized. It seems somewhat imprudent to assume any cannibalization in computing spares requirements; however, components with large numbers per aircraft probably should be undervalued to some extent since one cannibalized aircraft can yield the entire quantity per aircraft of an item's application.

The performance of a stockage posture should be evaluated both with and without the cannibalization assumption. A stockage posture that performs poorly without cannibalization will be improved more by cannibalization than one that performs well without it. Thus when cannibalization is assumed in an evaluation, the performances of two stockage postures may be almost indistinguishable when in fact they perform very differently without cannibalization.

What this logic suggests is that the stockage posture whose performance is poor without cannibalization *depends* on cannibalization to yield acceptable levels of performance in the operational world. The use of computational methods that result in such stockage postures implicitly shift some unknown but perhaps unacceptable share of the support burden from supply to maintenance, especially if the observations made in Section III turn out to be translatable to the operational environment.

There are unresolved issues affecting the choice of cannibalization policy. A reasonable policy might be to code for each component the probability of successful cannibalization along with its cost, and compute stockage postures in a way that explicitly accounts for those component characteristics. If such a scheme is not feasible, it seems imprudent to assume any cannibalization.

Military Essentiality

The Navy is currently involved in coding all aviation components with respect to military essentiality. Each component will be assigned a number between zero and one to describe its essentiality. Appendix C illustrates how simply the essentiality code can be included in the aircraft availability objective function of a stockage computational model, in this case one that assumes random shortages of items over aircraft. Military essentiality is a simple modeling problem; its difficult aspect lies in specifying truly meaningful essentiality codes.

The ability of an optimization algorithm to achieve higher availability for equal investment lies in its strategy of giving up a few very high cost items and stocking many more of the lower cost items, thus gaining advantage in both range and depth. However, if the highest cost items are the most essential, the optimization can be self-defeating. Thus such an algorithm should be coupled with a data base that accurately reflects item essentiality.

Modeling (S,s) Reorder Policies

The demonstration in this Note included only repairable items the reorder policy for which is assumed to be (S,S-1); i.e., the economic order quantity at the retail echelon is assumed to be one unit of stock. We approximated order quantities greater than one at the wholesale level by increasing the variance of the number of units in resupply at the wholesale level by the variance of a uniform distribution from zero to the reorder quantity. The same technique may be appropriate for the retail level.

An alternative approach is to separate the computation of repairables from that of consumables but to estimate the effects of shortages of consumables on aircraft availability and include that estimate in the repairable computation. This is a research issue that needs resolution but is beyond the scope of the present work.

The Forecasting Problem

Another problem that remains unsolved is the problem of forecasting future values of item and system characteristics. The problem is simple to describe but difficult to solve. It is that the computation one makes today is based on past observations and, perhaps, some predictions of the future. If a mix of spares is ordered now based on those observations, it will almost inevitably be the wrong mix when the spares are finally acquired because the future will eventuate in ways that we cannot predict. It is important, as we said before, that the data base that supports spares computations be as realistic a model of the future as we know how to make it.

But even if we are exceptionally conscientious in maintaining the data base, item characteristics evolve in ways that we simply cannot foresee. Items disappear entirely from the data base; new items appear; and item removal rates, BCM rates, procurement prices, repair times, and other characteristics change. It is important that the problem of characterizing such changes be solved because of the need to program funds for the provisioning and replenishment of spares. The leadtimes involved are such that the forecasting problem underlies the inability of the system to reach the right decisions about either investment levels or mixes of spares, and the further in the future the point in time is for which we try to estimate the availability-cost relationship, the more inhibiting the lack of a solution to the forecasting problem becomes.

What is needed is the ability to characterize statistically how the data base might change as time passes. If that were possible, it might also be possible to generate random realizations of data bases that would be representative of possible futures and that could support estimates of availability-cost relationships as they *might* be computed at future buy points. Such an approach would enable the kinds of techniques discussed in Section III to be very useful in planning, programming, and budgeting as well as in the computations of levels and requirements. They could bring consistency to the decisionmaking about availability goals and investment levels across the several stages of PPBE&M, the need for which we discussed at length in Section I.

The Computational Software

The results of the demonstration of Section III suggest that a stockage computational algorithm for naval aviation should:

- Be multi-item, multi-location, multi-echelon, and multi-indenture.
- Encompass both repairables and consumables.
- Account for item commonality.
- Incorporate a weapon system availability objective function.
- Produce an availability-cost curve by weapon system, each point of which is an optimum, rather than relying on a Lagrangian function.
- Account for heterogeneous distributions of end items.
- Have the ability to compute stockage postures for individual retail sites with visibility of item-specific depot delay times.
- Accommodate a cannibalization assumption for those items specified by policy.
- Provide decision support for the allocation of resources and goal setting across weapon systems.
- Model item-specific variance-to-mean ratios of the distribution of the number of items of each type in resupply.
- Be coupled with a data base that reflects both military essentiality and cannibalization data as well as the necessary 3M and program data elements needed to support the multi-echelon computation.
- Be routinely used in practice with a capability assessment model that takes explicit account of the dynamic character of combat scenarios.

With some modifications (for cannibalization, consumables, and heterogeneous end item distribution), the LMI Aircraft Availability Model would satisfy all of these criteria. Moreover, the latest version of Dyna-METRIC could be used for capability assessments both with and without cannibalization, either complete or partial. We do not wish to advocate *particular* models; however, there are clearly some advantages to be gained in adapting existing, computationally efficient models to the problem rather than starting from scratch. Except for validation in the naval aviation context, the task of developing the logic of computational algorithms is modest. Clearly, neither of these models is suitable for direct installation in production systems but could provide the computational algorithms and logic for production versions.

DATA BASES

No single Navy data base can support a multi-echelon computation. What is needed is a combination of program data, wholesale and retail supply data, and 3M data. Thus several data files need to be brought together to produce the data base that is needed. Perhaps the most important single conclusion of this work is that, as an absolute minimum, the Navy needs to provide item-specific depot delay times to the computation of retail allowances. That visibility, coupled with an aircraft availability objective function, optimization algorithm, and realistic wartime scenario, could yield the most significant gains in performance of any of the changes discussed in this Note.

SCENARIOS

The estimated performance of every alternative stockage computational technique examined in Section III was superior to the "Navy" method, even those that were considerably less than "optimal." An important reason for this is that the higher aircraft utilization rates postulated for the wartime scenario were used as the basis for the computations in all but the "Navy" case. In the "Navy" approach, the peacetime flying hour program is the basis of the wholesale computation; then war reserve stocks are added. The result seems quite predictable. A stockage posture that is optimized for the higher activity level will perform better at that activity level than one that is not. Thus wartime scenarios should be used for computing stockage postures throughout the system.

This logic has implications for war reserve stockage policy. In a stockage optimization computation done at wartime activity levels, war reserve is essentially built into the resulting stockage posture rather than being added to it after the fact. It may be desirable, however, to protect some stock against depletion in peacetime due to extreme variability in the numbers of items in peacetime resupply. Inviolate war reserve levels could be established on the basis of two successive stockage optimizations, one at the wartime activity level and one at the peacetime activity level, the differences in the resulting stockage postures being identified as war reserve.

V. UNCERTAINTY AND ITS IMPLICATIONS FOR AVIATION LOGISTICS

In this section we broaden our focus from spares stockage computational issues to the total logistics system. We begin with some observations of variability in resource demands. During the course of this research, we examined 3M data on several arbitrarily selected, WRAs on the F-14 aircraft. The data revealed levels of variability in component removal rates far beyond the levels planned for in determining allowances. This finding, however preliminary and tentative, implies the need for enhanced flexibility and responsiveness in aviation logistics as well as different views of stockage policies and spares requirements determinations.

OBSERVED VARIABILITY IN DEMAND

The findings reported here are based on 3M data collected at NAS Oceana and Miramar during the 28-month period from August 1981 through November 1983, and from two consecutive deployments of each of two CVs, the U.S.S. Nimitz and the U.S.S. Eisenhower, all four of which took place during the same 28-month period. The work unit codes (WUCs) included in this analysis were chosen quite arbitrarily from among weapon-replaceable assemblies on the F-14 aircraft.

The data consisted of detail records reflecting on-aircraft component removals for cause, i.e., no-defect removals were excluded.[1] The data set contained the date of each removal action, by bureau number, by location. The data were arranged chronologically by location, and grouped into complete weeks, months, and quarters. Then the mean removal rate and variance were computed by week, month, and quarter. Finally, the unbiased estimate of the variance was divided by the unbiased estimate of the mean, and the ratio used as an estimator of the variance-to-mean ratio (VTMR) of the component removal process. Unfortunately, this estimator is not only biased for certain processes, it also has very high variance [12].

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[1] The specific rules used for the selection of records are described in Appendix F.

The computation of retail allowances is based on the classical assumption of a simple Poisson process. Under this assumption the variance of the demand distribution equals its mean, i.e., the VTMR is unity. This assumption is important to the computation of safety levels as well as estimates of stockage posture performance characteristics such as fill rates, expected backorders, operational rates, and weapon system availabilities. It is a measure of the uncertainty of demand. The higher the VTMR, the less predictable the demand.

For purposes of exposition, we show in Table 10 data from NAS Oceana. Similar results are shown for other locations in Appendix F. Note that the estimated VTMR increases as a function of the time period over which the data are aggregated. This is partially explained by the fact that the VTMR estimator is biased, and the amount of its bias decreases with the length of the time period; however, there are other factors operating here, for example, nonstationarity in the component removal process, batching of removals by maintenance, or, perhaps, data problems. Thus the significance of the VTMRs shown in Table 10 is not clear. The estimates based on quarterly data are probably better approximations than those based on the shorter time periods; on the other hand, the estimates based on longer periods are more susceptible to errors induced by changes in location parameter.

The results shown in Table 10 are corrected for flying hours in Table 11. The correction makes a significant difference which suggests that variability in flying activity plays some role here, but, in the quarterly data, 19 of the 26 components still have variance-to-mean estimates at least twice the value assumed in the computation of retail allowances, and the estimator, as pointed out previously, is negatively biased.

The quantification of VTMR may have little intuitive meaning to the reader. To illustrate the point we are trying to make here we show in Figure 7 a graph of the number of removals per quarter of work unit code 56X21 for the nine-quarter period of the data set, again using the Oceana data. What this graph portrays is the actual number of removals for

Table 10

UNADJUSTED REMOVALS, OCEANA NAS

WUC	Estimated Weekly Mean	Estimated Weekly VTMR	Estimated Monthly Mean	Estimated Monthly VTMR	Estimated Quarterly Mean	Estimated Quarterly VTMR
56X21	8.1	4.7	32.8	10.9	104.7	18.5
56X25	5.7	2.8	22.9	7.3	74.2	17.5
56X44	0.4	11.0	1.6	45.0	5.8	52.0
69163	0.9	1.7	3.8	3.0	12.3	6.0
69182	4.4	2.7	17.5	6.7	56.6	17.9
713C1	2.4	1.7	9.8	3.9	32.3	7.8
734H1	5.9	1.7	23.6	2.8	76.3	4.6
74A1C	8.3	3.3	33.0	8.5	108.9	17.4
74A1G	4.8	1.8	19.4	3.2	64.2	5.8
74A1J	1.5	2.1	5.9	3.3	19.4	5.5
74A1Q	14.1	3.7	56.5	6.6	183.7	9.2
74A1U	5.8	2.8	23.2	5.9	74.8	11.3
74A1V	6.3	2.6	25.0	4.5	82.3	8.0
74A1Z	0.1	1.0	0.2	1.1	0.8	1.5
74A11	5.6	2.7	22.4	5.4	72.0	14.3
74A15	6.4	4.9	25.6	6.8	83.2	9.2
74A4E	6.5	2.8	26.0	5.6	81.8	10.1
74A45	3.1	3.1	12.4	5.7	39.9	11.5
74A48	3.8	2.1	15.2	4.2	49.8	7.1
74A5M	7.0	2.5	28.0	4.9	93.4	9.8
74A55	3.3	1.4	13.2	1.9	43.1	2.0
74A74	2.0	1.5	8.1	2.1	26.2	3.3
74A75	1.0	2.1	4.2	5.1	13.7	9.3
74A78	.02	1.0	0.1	1.0	0.2	0.9
763W1	0.2	1.0	1.0	1.5	3.2	1.5
76731	0.3	2.9	1.3	4.8	4.2	3.6

cause of this work unit code in each of the nine quarters, and also portrays a random realization of a process with the same mean and a VTMR of unity. In other words, we contrast the actual component removal process with a "planned" process in the sense that the variability of the planned process is of the order of magnitude assumed in the computation of retail allowances. We do not know what mean might have been used for any particular provisioning of this component; therefore, we use the same mean for the "planned" process as observed in the actual process. The contrast is stark and shows the fallacy of the Poisson assumption.

Table 11

REMOVALS PER 1000 FLYING HOURS, OCEANA NAS

WUC	Estimated Weekly Mean	Estimated Weekly VTMR	Estimated Monthly Mean	Estimated Monthly VTMR	Estimated Quarterly Mean	Estimated Quarterly VTMR
56X21	17.8	3.2	17.8	7.2	18.3	10.7
56X25	12.4	2.2	12.4	4.3	12.3	8.3
56X44	0.9	8.3	0.9	33.4	0.3	9.9
69163	2.1	1.1	2.0	1.5	2.1	2.8
69182	9.5	1.8	9.5	3.5	9.3	5.3
713C1	5.3	1.2	5.3	1.9	5.3	2.7
734H1	12.8	1.4	12.8	1.3	12.7	1.0
74A1C	18.0	2.0	18.0	3.5	18.2	6.1
74A1G	10.6	1.7	10.5	2.0	10.5	2.7
74A1J	3.2	1.6	3.2	2.0	3.3	3.5
74A1Q	30.6	2.8	30.7	3.5	30.8	5.2
74A1U	12.6	1.8	12.6	2.9	12.7	3.1
74A1V	13.7	1.9	13.6	2.2	13.6	1.6
74A1Z	0.1	1.0	0.1	1.4	0.1	1.3
74A11	12.2	2.5	12.2	3.6	12.0	2.8
74A15	13.9	2.8	13.9	4.5	14.1	5.0
74A4E	14.1	2.1	14.1	3.7	14.1	5.0
74A45	6.7	2.0	6.7	3.4	6.7	6.1
74A48	8.3	1.7	8.2	2.5	8.3	1.4
74A5M	15.3	1.9	15.2	3.2	15.2	3.9
74A55	7.2	1.2	7.2	1.9	7.3	1.7
74A74	4.4	1.2	4.4	1.3	4.4	0.5
74A75	2.3	1.6	2.3	3.1	2.3	3.2
74A78	.03	1.0	.04	0.8	.04	2.2
763W1	0.5	1.0	0.5	1.1	0.5	1.2
76731	0.7	2.2	0.7	3.5	0.7	2.0

THE IMPLICATIONS OF UNCERTAINTY

The implication of variability of this magnitude is that it is very difficult to forecast demands, even in the short term. Yet the system presupposes the ability to make such forecasts, and behaves as though past demands predict future demands and peacetime demands predict wartime demands. The uncertainties in the system even in peacetime refute that supposition. Moreover, the uncertainties in peacetime will be compounded by the disruptions, resource losses, and inevitable surprises of combat. They cast doubt on the wisdom of depending on a spares solution alone to the problem because of the substantially higher

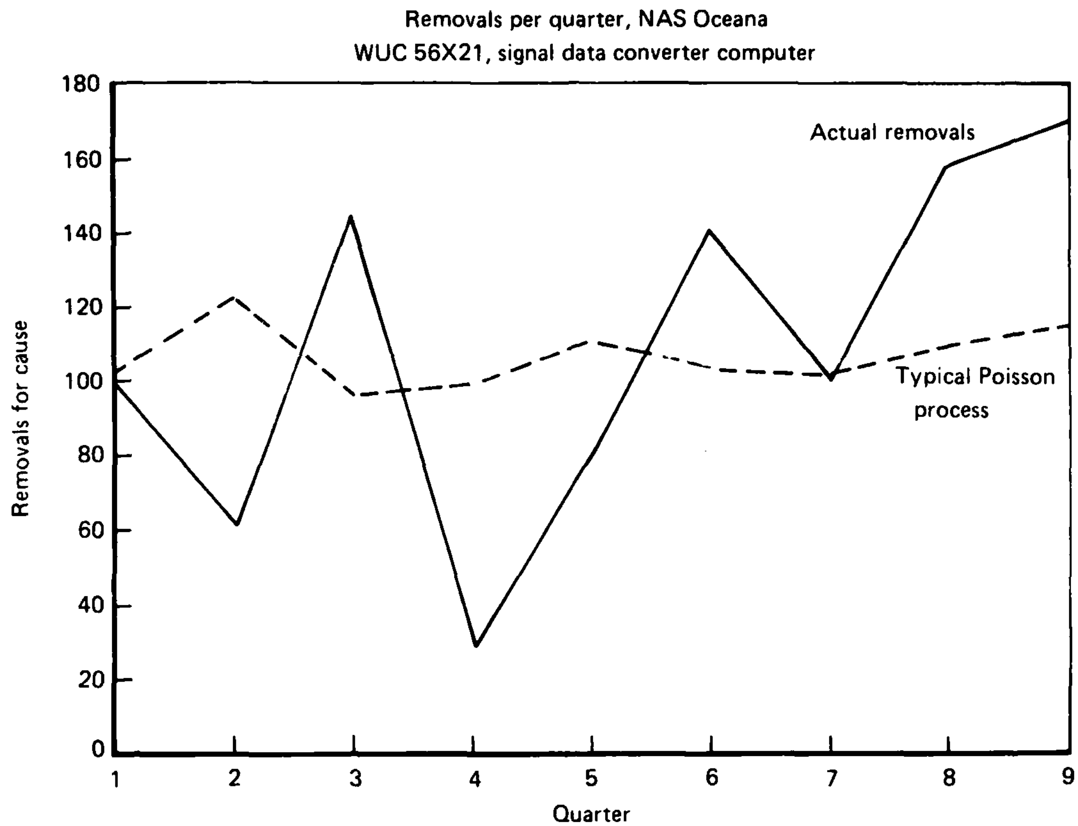

Fig. 7 — Quarterly removals, WUC 56X21, and a typical Poisson process

costs associated with stockage postures that try to provide a hedge against the demand variability. Thus the need exists to examine other solutions involving more flexible resources than spares, such as maintenance and distribution/transportation.

Demand uncertainty of this magnitude implies the need for enhanced flexibility and responsiveness in the naval aviation logistics system which presupposes a level of integration that the Navy does not now enjoy. Thus the thrust of this work in stockage computational techniques should be viewed in the broader context of the enhanced integration needed in the system as a prerequisite of sorts to improving the system's flexibility and responsiveness. Its implications in the larger context are both for aviation supply within itself and for the interrelationships between supply and other functional areas.

But what of the implications for stockage computations of the levels of demand variability we have shown here? No matter how responsive the system can be made, the stockage computational problem never disappears. There will always be a need for spares. The question is how to formulate a reasonable set of assumptions on which to base the computational approach, including assumptions that take advantage of what we know about demand variability. One of the factors that contributed to the better performances of the alternative techniques demonstrated in Section III over the "Navy" method is that the alternative methods do not make the simple Poisson assumption in computing retail allowances. Instead, they assign a variance-to-mean ratio to the distribution of the number of items in resupply of each type that was related to the item's mean demand rate according to the formula described in Appendix B, i.e., the assigned variance-to-mean ratio was invariably greater than unity.

However, taking explicit account of higher variance-to-mean ratios in computing stockage postures yields higher estimates of investment levels for specified levels of weapon system availability. If the levels of variability we have shown here are pervasive, their use in stockage computations might very well put stockage solutions out of reach in terms of their costs. On the other hand, there may be a simple method for taking explicit account of demand variability in stockage computations in a way that does not make the solutions exorbitantly costly but does yield stockage postures that are sufficiently robust in the face of uncertainty. The solution to this problem is not clear. Additional analysis is needed to determine the extent and magnitude of the variability as well as its persistence over time. We also need to understand better the implications of the variability for stockage computations.

The cost of hedging against the levels of uncertainty that we have seen here might be more than offset by pursuing strategies that reduce item pipelines and that enhance the selective responsiveness of the system to unanticipated demands. In other words, system performance might best be enhanced by *combinations* of techniques that (a) take explicit account of uncertainty in stockage computations, (b) reduce component repair times, order-and-ship times, and retrograde times, and (c) enhance the ability of the system to respond selectively to unanticipated demands in ways that contribute best to the combat posture of the fleet. Thus the observations made here about demand variability do not necessarily mean that optimization models are inappropriate for use in stockage computations because of the difficulty in forecasting demand. They simply imply that we need to understand the character of the variability better as well as its implications for stockage computations, and that *solutions should be sought in other areas as well as in supply*.

This argument is reinforced by the fact that the uncertainties the system faces in peacetime are compounded by the uncertainties of combat. The reduction of item pipelines and an enhanced ability to respond to unanticipated demands, coupled with improved stockage computational methods, can mitigate the effects of those uncertainties.

VI. TOWARD ENHANCED INTEGRATION AND RESPONSIVENESS IN AVIATION LOGISTICS

The Navy needs to establish a program of research and development that will help it move toward enhanced integration and responsiveness in aviation logistics. The areas of research should include: enhanced system integration through capability assessment; improved spares stockage computational techniques; and more responsive repair, distribution, and transportation systems. The specific objectives of this research program should be to:

- Implement capability assessment techniques at key decision points throughout naval aviation, including stockage determinations, to enhance system integration.
- Understand better the implications of uncertainty on the stockage computational problem.
- Develop multi-echelon spares stockage optimization models for computing wholesale reorder levels and retail allowances that maximize weapon system availability and that are consistent with the outcomes of the research in uncertainty mentioned above.
- Develop integrated data bases that bring together the data required to support such computational techniques including military essentiality data.
- Develop strategies for improving the responsiveness of depot repair and distribution/transportation, thus coupling the depot more closely to the combat force to meet unanticipated critical demands more responsively.

As pointed out previously, demand uncertainty implies the need for enhanced flexibility and responsiveness in the naval aviation logistics system, responsiveness which presupposes a level of integration that the Navy does not now enjoy. Thus the work being proposed here should have as its basic thrust two principal goals:

- Enhancement of integration through systemwide capability assessment and improved stockage computational techniques.
- Enhancement of flexibility and responsiveness throughout the system, but especially in depot-level component repair and distribution/transportation.

A RESEARCH AND DEVELOPMENT PROGRAM

The objectives of this work could be met through three major tasks that we recommend the Navy undertake, two of which are concerned primarily with integration, and one with responsiveness.

Task 1: Enhancing Integration Through Systemwide Capability Assessment

In this task, the Navy would undertake the first steps toward enhancement of aviation logistics system integration and oversight through initiation of capability assessments. These assessments would be used by key decisionmakers throughout the operational logistics system to support the consistency in decisionmaking for which we described the need in Section I. The steps involved would be:

- Acquisition of data by NAVAIR to support the assessment of both the peacetime and wartime weapon system sortie generation capability of a major weapon system, both afloat and ashore.
- In concert with at least one TYCOM and the ASO weapon system management organization, completion of this prototype assessment by NAVAIR.
- Analysis of the results of the assessment to identify resource constraints, problem parts and causes, and related policy issues, as well as technical problems in conducting the assessment.
- Based on successful completion of these initial tasks, identification of specific steps to be taken to implement capability assessment techniques at key decisionmaking points in the system.

- Additional technical support and training of Navy personnel as required to assure a smooth transition to routine maintenance, support, and use of the techniques at key decision points throughout the system.

This approach could be expected to:

- Identify quickly what the key implementation issues are, e.g., data quality and accessibility.
- Support aviation logistics planning in a useful and constructive application.
- Demonstrate the ability of capability assessment techniques to make a genuine contribution to enhancement of aviation logistics system integration.
- Provide the Navy with the needed ability to bring combat capability orientation to its key decisionmaking.

Task 2: Improving Spares Stockage Postures

The observations of demand uncertainty shown in Section V are persuasive, but the analysis needs to be extended because the implications to capability are so important. Additional analysis is needed to provide evidence on the pervasiveness, magnitude, and persistence of the variability, and the ability of the current system to cope with it.

This task would involve understanding better the character of the variability and its implications to the stockage computational problem, as well as the analysis of the implementation issues discussed in Section IV. This research would be followed by or coupled with the development and implementation of multi-echelon spares stockage computational models that maximize weapon system availability and explicate availability/cost relationships to support resource allocation decisionmaking as well as stockage posture determinations. It would involve the development of computational algorithms having the characteristics described in Section IV. Following the research phase described above, the several steps involved in this task would be:

- Development of an integrated data base that would bring together 3M data, program data, and supply data to support a multi-echelon availability optimization.
- Specification of military essentiality and cannibalization coding and inclusion of those codes in the data base.
- Enhancement and adaptation of a model such as the LMI Aircraft Availability Model so that it explicitly accommodates military essentiality, cannibalization, (S,s) reorder policies, heterogeneous end item distribution, and separable optimization of AVCAL and OSI stockage postures.
- Calibration of the model to the naval aviation environment.
- Implementation of the model coupled with implementation and routine use of the Dyna-METRIC model or a similar model for estimating the performance of stockage postures in combat scenarios.

Task 3: Enhancing Responsiveness in Distribution/Transportation and Depot-Level Component Repair

In this task the Navy would:

- Analyze the current logistics system to determine the nature of demand and pipeline variability and the lengths of all segments of the logistics pipeline, with special attention to the order-and-ship, retrograde, and depot repair segments.
- Determine how well (and in what ways) the current system responds to urgent demands--both anticipated and unanticipated--in order to understand the implications to both cost and effectiveness of (a) enhanced selective response to unanticipated demands and (b) reductions to pipeline times.

The following tasks are likely to emerge from these initial efforts:

- Assessment of the distribution/transportation system to identify alternatives that could improve its responsiveness and shorten pipeline times for both serviceable and retrograde spares and other logistics resources, and estimation of the gains achievable.
- Assessment of the depot-level component repair system with the similar goal of identifying alternatives that could improve its responsiveness to demands from the fleet, and, again, estimation of the gains achievable.
- Determination of the applicability of identified alternatives to intermediate-level repair activities.

CONCLUDING REMARKS

In this Note, we have tried to demonstrate:

- The worth of an aircraft availability objective function coupled with a multi-echelon optimization algorithm and integrated data base in stockage computations.
- The need for enhanced flexibility and responsiveness in the system implied by the levels of demand variability observed in peacetime which, when compounded with the uncertainties of combat scenarios, inhibit effective support.
- The value of reducing item pipelines in conjunction with improving stockage postures in mitigating the effects of uncertainty, especially in combat scenarios.

The use of improved techniques of the kind described in this Note can move the aviation supply community toward more ultimate, capability-oriented measures that have operational meaning throughout the system. Moreover, those techniques can be expected to deliver substantially improved performance at current levels of investment in both peacetime and wartime, and enhance both intrafunctional and interfunctional supply system integration.

Appendix A

EMULATING THE NAVY'S STOCKAGE COMPUTATIONS

At present the Navy separates its stockage computations by echelon. To emulate the Navy's methods, we employed two software modules: the first was based upon the Uniform Inventory Control Program and was used to generate wholesale stock levels; the second was an existing Rand model of the procedure used to determine OSIs and AVCALs.

In addition to scenario- and component-specific data, each module requires a number of performance-related parameters. In the case of the wholesale emulator, these are quantities such as shortage costs and bounds on stockout risk. In our demonstration, we used values identical to those established by ASO for the September 30, 1983, Strat run. These are discussed in greater detail in Appendix D. The OSI/AVCAL emulator requires a fill rate goal and a target endurance period, as well as a specification of whether or not safety stock is to be added. We postulated a fill rate of 0.85 for both naval air stations and aircraft carriers, and endurance periods (including order-and-ship time) of 40 days for shore stations and 105 days for carriers. As does ASO, we added safety stock to the repair pipeline only.

The FORTRAN code for both emulators is given below. In each case, extensive comments have been provided to aid the understanding of interested readers.

EMULATING THE NAVY'S WHOLESALE REORDER LEVEL COMPUTATIONS

```
C
C     PROGRAM FULL.UICP.MIMIC (the wholesale emulator)
C
C****************************************************************************
C*
C*    PROGRAM FULL.UICP.MIMIC IS A REPRESENTATION OF THE NAVY'S
C*    UNIFORM INVENTORY CONTROL PROGRAM (UICP) PROCEDURE FOR
C*    DETERMINING CONSTRAINED REORDER LEVELS FOR RECOVERABLE ITEMS.
C*    THE CALCULATIONS INVOLVED ARE DRAWN FROM UICP DOCUMENTATION
```

```
C*    (PUBLICATION FMSO-FD-B20) PROVIDED BY THE FLEET MATERIAL
C*    SUPPORT OFFICE, AND INCLUDE SPECIFICALLY FORMULAS 10A,11,13,
C*    14, AND 17B OF APPENDIX F, REORDER LEVEL AND ORDER QUANTITY
C*    COMPUTATION.  OBSERVE THAT IN FULL.UICP.MIMIC, CONSTRAINED
C*    REORDER LEVELS ARE CALCULATED FROM USER-SPECIFIED SHORTAGE
C*    COSTS RATHER THAN FROM PREVIOUSLY ESTABLISHED BASIC REORDER
C*    LEVELS.
C*
C******************************************************************************
C
      INTEGER
     1    FPNUM,LMNUM,INDEX,I,J
C
      DOUBLE PRECISION
     1    BNUM,CNUM,ACFTPB,ACFTPC,BFHAM,CFHAM,TPR,CST,DISTRB,PR,
     1    PRICE,RMIN,RMAX,SLF,AIE,EUR,RLLL,OBR,QPA,PROCLT,ORDQTY,
     1    DRSR,DCR,DTAT,BBCM,CBCM,BRPAFH,CRPAFH,A0,A99,DUMMY,BREMRT,
     1    CREMRT,DDDR,PVPSR,VPSR,APSR,MEAN,VARIAN,VTM,CSH,CAND1,
     1    CAND2,CAND3,CAND4,CAND5,CAND6,SD,FBRL,BRL,FCRL,CRL,
     1    FPF(9),NORCDF(51)
C
      CHARACTER*4
     1    NAME(7)
C
C******************************************************************************
C*
C*    GLOSSARY OF VARIABLES IN FULL.UICP.MIMIC:
C*
C*    FPNUM:    NUMBER OF FLYING PROGRAMS
C*    LMNUM:    NUMBER OF LAGRANGE MULTIPLIERS
C*    INDEX:    COUNTING INDEX FOR ITEMS
C*    I:        DO LOOP INDEX
C*    J:        DO LOOP INDEX
C*    BNUM:     NUMBER OF BASES
C*    CNUM:     NUMBER OF CARRIERS
```

```
C*   ACFTPB:  NUMBER OF AIRCRAFT PER BASE
C*   ACFTPC:  NUMBER OF AIRCRAFT PER CARRIER
C*   BFHAM:   FLYING HOURS PER AIRCRAFT PER MONTH AT A BASE
C*   CFHAM:   FLYING HOURS PER AIRCRAFT PER MONTH ON A CARRIER
C*   TPR:     TIME PREFERENCE RATE (V101A)
C*   CST:     STORAGE COST PER UNIT, EXPRESSED AS A FRACTION OF
C*               REPLACEMENT PRICE (PROGRAMMED CONSTANT)
C*   DISTRB:  DISTRIBUTION SELECTION LEVEL (NORMAL OR NEGATIVE
C*               BINOMIAL)
C*   PR:      NUMBER OF POLICY RECEIVERS
C*   PRICE:   REPLACEMENT PRICE PER UNIT (B055)
C*   RMIN:    MINIMUM ALLOWABLE STOCKOUT RISK (V022)
C*   RMAX:    MAXIMUM ALLOWABLE STOCKOUT RISK (V102)
C*   SLF:     SHELF LIFE FACTOR (YEARS) (C028)
C*   AIE:     AVERAGE ITEM ESSENTIALITY (C008C)
C*   EUR:     EXPECTED NUMBER OF UNITS PER REQUISITION (B073)
C*   RLLL:    REORDER LEVEL LOW LIMIT (B020)
C*   OBR:     OBSOLESCENCE RATE (B057)
C*   QPA:     QUANTITY PER APPLICATION
C*   PROCLT:  PROCUREMENT LEAD TIME FORECAST (DAYS) (B011A)
C*   ORDQTY:  SYSTEM ORDER QUANTITY (B021)
C*   DRSR:    DEPOT REPAIR SURVIVAL RATE (F009)
C*   DCR:     DEPOT CONDEMNATION RATE
C*   DTAT:    DEPOT TURNAROUND TIME (DAYS) (B012F)
C*   BBCM:    BASE BCM RATE
C*   CBCM:    CARRIER BCM RATE
C*   BRPAFH:  ITEM REMOVALS PER AIRCRAFT FLYING HOUR AT A BASE
C*   CRPAFH:  ITEM REMOVALS PER AIRCRAFT FLYING HOUR ON A CARRIER
C*   A0:      CONSTANT EQUAL TO 0.0
C*   A99:     CONSTANT EQUAL TO 99.0
C*   DUMMY:   DUMMY VARIABLE IN A READ STATEMENT
C*   BREMRT:  ITEM REMOVALS PER DAY AT A BASE
C*   CREMRT:  ITEM REMOVALS PER DAY ON A CARRIER
C*   DDDR:    DEPOT DAILY DEMAND RATE
C*   PVPSR:   PRELIMINARY VARIABLE PROCUREMENT STOCKOUT RISK,
```

```
C*              CALCULATED WITH SHORTAGE COST SET EQUAL TO 1.0
C*    VPSR:    VARIABLE PROCUREMENT STOCKOUT RISK
C*    APSR:    ACCEPTABLE PROCUREMENT STOCKOUT RISK
C*    MEAN:    EXPECTED NUMBER OF UNITS IN THE DEPOT RESUPPLY
C*                PIPELINE
C*    VARIAN:  VARIANCE OF THE NUMBER OF UNITS IN THE DEPOT
C*                RESUPPLY PIPELINE
C*    VTM:     VARIANCE-TO-MEAN RATIO FOR THE NUMBER OF UNITS IN
C*                THE DEPOT RESUPPLY PIPELINE
C*    CSH:     SHORTAGE COST PER UNIT (V104)
C*    CAND1:   INTERMEDIATE
C*    CAND2:      CANDIDATES IN
C*    CAND3:         THE CALCULATION
C*    CAND4:            OF CONSTRAINED
C*    CAND5:               REORDER
C*    CAND6:                  LEVELS
C*    SD:      SAFETY STOCK, EXPRESSED IN STANDARD DEVIATIONS ABOVE
C*                THE MEAN, IMPLIED BY THE ACCEPTABLE PROCUREMENT
C*                STOCKOUT RISK
C*    FBRL:    FRACTIONAL BASIC REORDER LEVEL
C*    BRL:     BASIC REORDER LEVEL
C*    FCRL:    FRACTIONAL CONSTRAINED REORDER LEVEL
C*    CRL:     CONSTRAINED REORDER LEVEL
C*
C*    FPF(9):      FLYING PROGRAM FACTORS
C*    NORCDF(51):  CUMULATIVE DISTRIBUTION FUNCTION FOR THE
C*                    STANDARD NORMAL DISTRIBUTION, TABULATED
C*                    IN TENTHS OF STANDARD DEVIATIONS ABOVE
C*                    THE MEAN FROM 0.0 TO 5.0
C*    NAME(7):     ITEM NAME, CONSISTING OF NIIN AND A BRIEF
C*                    DESCRIPTION (D046D/C002B,C004)
C*
C*********************************************************************
C
C
```

```
C**** SET CONSTANTS ****
C
      A0=0.
      A99=99.
C
C**** GENERATE THE CUMULATIVE DISTRIBUTION FUNCTION ****
C**** TABLE FOR THE STANDARD NORMAL DISTRIBUTION    ****
C
      CALL NTABLE (NORCDF)
C
C**** READ SCENARIO DATA ****
C
      READ (1,110) FPNUM,LMNUM
  110 FORMAT (2I1)
      DO 200 I=1,FPNUM
         READ (1,120) FPF(I)
  120    FORMAT (F6.3)
  200 CONTINUE
      READ (1,210) BNUM,CNUM,ACFTPB,ACFTPC,BFHAM,CFHAM
  210 FORMAT (4F5.0,2F7.2)
      READ (1,220) DUMMY
  220 FORMAT (F5.3)
      READ (1,230) TPR,CST,DISTRB,PR
  230 FORMAT (2F6.4,F8.2,F5.0)
C
C**** ECHO SCENARIO DATA ****
C
      WRITE (10,240) FPNUM,LMNUM
  240 FORMAT ('0',5X,'FLYING PROGRAMS:  ',I1,10X,'LAGRANGE ',
     1   'MULTIPLIERS:  ',I1)
      WRITE (10,250)
  250 FORMAT ('0',5X,'FLYING PROGRAM FACTORS:')
      DO 300 I=1,FPNUM
         WRITE (10,260) I,FPF(I)
  260    FORMAT (12X,I1,'.',2X,F6.3)
```

```
 300  CONTINUE
      WRITE (10,310) BNUM,ACFTPB,BFHAM
 310  FORMAT ('0',5X,'BASES:',F5.0,3X,'AIRCRAFT PER BASE:',F5.0,
     1   3X,'FLYING HOURS PER AIRCRAFT-MONTH:',F7.2)
      WRITE (10,320) CNUM,ACFTPC,CFHAM
 320  FORMAT ('0',5X,'CARRIERS:',F5.0,3X,'AIRCRAFT PER CARRIER:',
     1   F5.0,3X,'FLYING HOURS PER AIRCRAFT-MONTH:',F7.2)
      WRITE (10,330) TPR
 330  FORMAT ('0',5X,'TIME PREFERENCE RATE:',2X,F6.4)
      WRITE (10,340) CST
 340  FORMAT ('0',5X,'STORAGE COST (AS % OF ITEM PRICE):',2X,F6.4)
      WRITE (10,350) DISTRB
 350  FORMAT ('0',5X,'DISTRIBUTION SELECTION LEVEL:',2X,F8.2)
      WRITE (10,360) PR
 360  FORMAT ('0',5X,'NUMBER OF POLICY RECEIVERS:',2X,F5.0)
C
C**** BEGIN A LOOP TO READ ITEM DATA ****
C
      INDEX=0
 400  INDEX=INDEX+1
      READ (2,410,END=900) NAME(1),NAME(2),NAME(3),NAME(4),
     1   NAME(5),NAME(6),NAME(7),PRICE,RMIN,RMAX,SLF,AIE,EUR,
     1   RLLL,OBR,QPA,PROCLT,ORDQTY,DRSR,DCR,DTAT,BBCM,CBCM,
     1   BRPAFH,CRPAFH
 410  FORMAT (7A4,F9.2,2F3.2,F12.3,F4.3,2F9.0,F4.2,F4.0,F8.2,
     1   F9.0,2F4.2,F8.2,16X,2F6.4,12X,2F8.6)
C
C**** ECHO ITEM DATA ****
C
      WRITE (13,420) NAME(1),NAME(2),NAME(3),NAME(4),NAME(5),
     1   NAME(6),NAME(7),PRICE,RMIN,RMAX,SLF,AIE,EUR,RLLL,
     1   OBR,QPA
 420  FORMAT (1X,7A4,2X,F9.2,2(2X,F3.2),2X,F12.3,2X,F4.3,
     1   2(2X,F9.0),2X,F4.2,2X,F4.0)
      WRITE (14,430) NAME(1),NAME(2),NAME(3),NAME(4),NAME(5),
```

```
     1   NAME(6),NAME(7),PROCLT,ORDQTY,DRSR,DCR,DTAT,BBCM,CBCM,
     1   BRPAFH,CRPAFH
 430  FORMAT (1X,7A4,2X,F8.2,2X,F9.0,2(2X,F4.2),2X,F8.2,
     1   2(2X,F6.4),2(2X,F8.6))
C
C**** CALCULATE THE RETAIL DAILY REMOVAL RATES AND THE ****
C**** DEPOT DAILY DEMAND RATE                          ****
C
      BREMRT=(ACFTPB*BFHAM*BRPAFH)/30.42
      CREMRT=(ACFTPC*CFHAM*CRPAFH)/30.42
      DDDR=(BNUM*BREMRT*BBCM)+(CNUM*CREMRT*CBCM)
C
C**** CALCULATE A PRELIMINARY VARIABLE PROCUREMENT STOCKOUT ****
C**** RISK, WITH SHORTAGE COST SET EQUAL TO 1.0            ****
C
      PVPSR=((TPR+OBR+CST)*PRICE*EUR)/AIE
C
C**** LOOP THROUGH FLYING PROGRAMS ****
C
      DO 600 I=1,FPNUM
C
C   **** CALCULATE THE MEAN, VARIANCE, AND VARIANCE-TO-MEAN ****
C   **** RATIO OF THE NUMBER OF UNITS IN THE DEPOT RESUPPLY ****
C   **** PIPELINE                                           ****
C
        MEAN=DDDR*FPF(I)*((PROCLT*DCR)+(DTAT*DRSR))
        VARIAN=(MEAN*((DSQRT(MEAN)/4.)+1.))+((ORDQTY**2)/12.)
        VTM=VARIAN/MEAN
C
C   **** CONSTRAIN THE VARIANCE AND VARIANCE-TO-MEAN RATIO ****
C   **** IN SUCH A WAY THAT THE VARIANCE-TO-MEAN RATIO     ****
C   **** ALWAYS FALLS IN THE INTERVAL (1.01,25.0)          ****
C
        IF (VTM.LT.(1.01)) THEN
          VTM=1.01
```

```
            VARIAN=1.01*MEAN
         END IF
         IF (VTM.GT.(25.)) THEN
            VTM=25.
            VARIAN=25.*MEAN
         END IF
C
C   **** LOOP THROUGH LAGRANGE MULTIPLIERS ****
C
         DO 500 J=1,LMNUM
C
C      **** READ THE SHORTAGE COST FOR THE I'TH FLYING ****
C      **** PROGRAM AND THE J'TH LAGRANGE MULTIPLIER    ****
C
            READ (3,440) CSH
 440        FORMAT (F14.0)
C
C      **** CALCULATE THE TRUE VARIABLE PROCUREMENT ****
C      **** STOCKOUT RISK                           ****
C
            VPSR=PVPSR/CSH
            VPSR=DMIN1(VPSR,A99)
C
C      **** CALCULATE THE ACCEPTABLE PROCUREMENT ****
C      **** STOCKOUT RISK                        ****
C
            CAND1=VPSR/(VPSR+1.)
            CAND2=DMAX1(RMIN,CAND1)
            APSR=DMIN1(RMAX,CAND2)
C
C      **** CALCULATE THE BASIC REORDER LEVEL FOR THE ****
C      **** I'TH FLYING PROGRAM AND THE J'TH LAGRANGE ****
C      **** MULTIPLIER                                ****
C
            IF (MEAN.GE.DISTRB) THEN
```

```
C
C         **** THE NORMAL DISTRIBUTION IS SELECTED ****
C
               CALL STDEV (APSR,NORCDF,SD)
               FBRL=MEAN+(SD*DSQRT(VARIAN))
C
C         **** ROUND A FRACTIONAL BASIC REORDER LEVEL ****
C         **** TO THE NEXT HIGHER WHOLE NUMBER        ****
C
               BRL=FBRL
               IF ((BRL-DFLOAT(IDINT(BRL))).NE.(0.))
     1            BRL=DFLOAT(IDINT(BRL+1.))
               ELSE
C
C            **** THE NEGATIVE BINOMIAL DISTRIBUTION ****
C            **** IS SELECTED                        ****
C
                  CALL NEGBIN (APSR,MEAN,VTM,BRL)
            END IF
C
C      **** WRITE THE ROUNDED BASIC REORDER LEVEL INTO ****
C      **** A FILE SORTED BY ITEM, FLYING PROGRAM, AND ****
C      **** LAGRANGE MULTIPLIER                        ****
C
            WRITE (11,450) BRL
 450        FORMAT (F10.0)
C
C      **** CALCULATE THE CONSTRAINED REORDER LEVEL ****
C
            CAND3=DMAX1(FBRL,PR,A0)
            CAND4=((365.*DDDR*FPF(I)*DCR*SLF)+MEAN)-1.
            CAND5=(((365.*DDDR*FPF(I)*DCR)/OBR)+MEAN)-1.
            CAND6=DMIN1(CAND3,CAND4,CAND5)
            FCRL=DMAX1(RLLL,CAND6,A0)
C
```

```
C      **** ROUND A FRACTIONAL CONSTRAINED REORDER LEVEL ****
C      **** TO THE NEXT HIGHER WHOLE NUMBER              ****
C
             CRL=FCRL
             IF ((CRL-DFLOAT(IDINT(CRL))).NE.(0.))
     1          CRL=DFLOAT(IDINT(CRL+1.))
C
C      **** WRITE THE ROUNDED CONSTRAINED REORDER LEVEL ****
C      **** INTO A FILE SORTED BY ITEM, FLYING PROGRAM, ****
C      **** AND LAGRANGE MULTIPLIER                     ****
C
             WRITE (12,460) CRL
 460         FORMAT (F10.0)
C
C      **** PRINT THE BASIC AND CONSTRAINED REORDER LEVELS ****
C      **** FOR EACH ITEM, FLYING PROGRAM, AND LAGRANGE    ****
C      **** MULTIPLIER                                     ****
C
             WRITE (10,470) INDEX,I,J,BRL,CRL
 470         FORMAT (5X,I6,2(2X,I1),2(2X,F10.0))
 500      CONTINUE
 600  CONTINUE
      GOTO 400
 900  INDEX=INDEX-1
      WRITE (10,910) INDEX
 910  FORMAT ('0',5X,'TOTAL RECORDS PROCESSED: ',I6)
C
      STOP
      END
      SUBROUTINE NTABLE (NORCDF)
C
C***********************************************************************
C*
C*   SUBROUTINE NTABLE COMPUTES AND TABULATES THE VALUE OF THE
C*   STANDARD NORMAL CUMULATIVE DISTRIBUTION FUNCTION IN TENTHS
```

```
C*   OF STANDARD DEVIATIONS ABOVE THE MEAN FROM 0.0 TO 5.0.
C*   THE ARRAY OF VALUES IS RETURNED AS 'NORCDF'.
C*
C***********************************************************************
C
      INTEGER
     1   I
C
      DOUBLE PRECISION
     1   X,
     1   NORCDF(51)
C
C***********************************************************************
C*
C*   GLOSSARY OF VARIABLES IN NTABLE:
C*
C*   I:         DO LOOP INDEX
C*   X:         NUMBER OF STANDARD DEVIATIONS ABOVE THE MEAN
C*
C*   NORCDF(51):  CUMULATIVE DISTRIBUTION FUNCTION FOR THE
C*                  STANDARD NORMAL DISTRIBUTION, TABULATED
C*                  IN TENTHS OF STANDARD DEVIATIONS ABOVE
C*                  THE MEAN FROM 0.0 TO 5.0
C*
C***********************************************************************
C
      DO 100 I=1,51
         X=DFLOAT(I-1)/10.
         NORCDF(I)=.5+(.5*DERF(X/1.4142))
  100 CONTINUE
C
      RETURN
      END
      SUBROUTINE STDEV (APSR,NORCDF,SD)
C
```

```
C*****************************************************************
C*
C*   SUBROUTINE STDEV CALCULATES THE SAFETY STOCK, IN STANDARD
C*   DEVIATIONS ABOVE THE MEAN, REQUIRED BY A PARTICULAR VALUE
C*   OF THE ACCEPTABLE PROCUREMENT STOCKOUT RISK.  THIS QUANTITY
C*   IS RETURNED AS VARIABLE 'SD'.
C*
C*****************************************************************
C
      INTEGER
     1   I
C
      DOUBLE PRECISION
     1   APSR,SD,SAFETY,DIFF,
     1   NORCDF(51)
C
C*****************************************************************
C*
C*   GLOSSARY OF VARIABLES IN STDEV:
C*
C*   I:        DO LOOP INDEX
C*   APSR:     ACCEPTABLE PROCUREMENT STOCKOUT RISK
C*   SD:       SAFETY STOCK, EXPRESSED IN STANDARD DEVIATIONS ABOVE
C*                THE MEAN, IMPLIED BY THE ACCEPTABLE PROCUREMENT
C*                STOCKOUT RISK
C*   SAFETY:   SAFETY LEVEL CORRESPONDING TO THE ACCEPTABLE
C*                PROCUREMENT STOCKOUT RISK
C*   DIFF:     DIFFERENCE BETWEEN TWO AJACENT VALUES IN THE TABLE
C*                OF THE STANDARD NORMAL CDF
C*
C*   NORCDF(51):  CUMULATIVE DISTRIBUTION FUNCTION FOR THE
C*                    STANDARD NORMAL DISTRIBUTION, TABULATED
C*                    IN TENTHS OF STANDARD DEVIATIONS ABOVE
C*                    THE MEAN FROM 0.0 TO 5.0
C*
```

```
C*********************************************************************
C
C
C**** CALCULATE THE SAFETY LEVEL ****
C
      SAFETY=1.-APSR
C
C**** FIND SD, THE VALUE SUCH THAT THE NORMAL CDF(SD) ****
C**** IS EQUAL TO THE SAFETY LEVEL                   ****
C
      DO 100 I=2,51
         IF (NORCDF(I).GT.SAFETY) THEN
            DIFF=NORCDF(I)-NORCDF(I-1)
            SD=(DFLOAT(I-2)/10.)+((SAFETY-NORCDF(I-1))/(10.*DIFF))
            GOTO 999
         END IF
 100  CONTINUE
C
C**** IF NO VALUE HAS BEEN FOUND FOR SD, SET SD EQUAL TO ****
C**** THE DEFAULT VALUE OF 4.999                         ****
C
      SD=4.999
C
 999  RETURN
      END
      SUBROUTINE NEGBIN (APSR,MEAN,VTM,BRL)
C
C*********************************************************************
C*
C*   SUBROUTINE NEGBIN CALCULATES THE BASIC REORDER LEVEL FOR ITEMS
C*   WHOSE MEAN DEPOT RESUPPLY PIPELINE QUANTITIES HAVE THE NEGATIVE
C*   BINOMIAL DISTRIBUTION.  IN THIS FORMULATION, THE DISTRIBUTION
C*   PARAMETERS ARE EXPRESSED IN TERMS OF THE MEAN AND VARIANCE
C*   OF DEMAND.  THE BASIC REORDER LEVEL IS RETURNED AS VARIABLE
C*   'BRL'.
```

```
C*
C*******************************************************************************
C
      DOUBLE PRECISION
     1    APSR,MEAN,VTM,BRL,Q,P,K,LNTERM,SUM,SAFETY
C
C*******************************************************************************
C*
C*    GLOSSARY OF VARIABLES IN NEGBIN:
C*
C*    APSR:     ACCEPTABLE PROCUREMENT STOCKOUT RISK
C*    MEAN:     EXPECTED NUMBER OF UNITS IN THE DEPOT RESUPPLY
C*                  PIPELINE
C*    VARIAN:   VARIANCE OF THE NUMBER OF UNITS IN THE DEPOT
C*                  RESUPPLY PIPELINE
C*    VTM:      VARIANCE-TO-MEAN RATIO FOR THE NUMBER OF UNITS IN
C*                  THE DEPOT RESUPPLY PIPELINE
C*    BRL:      BASIC REORDER LEVEL
C*    Q:        VARIANCE-TO-MEAN RATIO
C*    P:        VARIANCE-TO-MEAN RATIO LESS ONE
C*    K:        RATIO OF MEAN TO P
C*    LNTERM:   NATURAL LOGARITHM OF A TERM IN THE NEGATIVE BINOMIAL
C*                  SUMMATION
C*    SUM:      RUNNING TOTAL OF THE NEGATIVE BINOMIAL SUMMATION
C*    SAFETY:   SAFETY LEVEL CORRESPONDING TO THE ACCEPTABLE
C*                  PROCUREMENT STOCKOUT RISK
C*
C*******************************************************************************
C
C
C**** CALCULATE THE SAFETY LEVEL ****
C
      SAFETY=1.-APSR
C
C**** CALCULATE THE DISTRIBUTION PARAMETER VALUES ****
```

```
C
      Q=VTM
      P=Q-1.
      K=MEAN/P
C
C**** SET THE BASIC REORDER LEVEL EQUAL TO ZERO.  THIS      ****
C**** WILL BE SUCCESSIVELY INCREMENTED UNTIL THE NEGATIVE   ****
C**** BINOMIAL SUMMATION IS EQUAL TO OR EXCEEDS THE SAFETY ****
C**** LEVEL.                                                ****
C
      BRL=0.
C
C**** CALCULATE THE NATURAL LOGARITHM OF THE INITIAL TERM ****
C**** OF THE SUMMATION.  THE LOGARITHMIC FORM IS USED IN  ****
C**** ORDER TO AVOID UNDERFLOW PROBLEMS.                  ****
C
      LNTERM=-1.*K*DLOG(Q)
C
C**** INITIALIZE THE SUMMATION ****
C
      SUM=DEXP(LNTERM)
C
C**** COMPARE THE SUMMATION WITH THE SAFETY LEVEL.  IF ****
C**** NECESSARY, INCREMENT BRL, CALCULATE THE NATURAL  ****
C**** LOGARITHM OF THE NEXT TERM, AND UPDATE THE       ****
C**** SUMMATION.  REPEAT AS NEEDED.                    ****
C
  100 IF (SUM.GE.SAFETY) GOTO 999
      BRL=BRL+1.
      LNTERM=LNTERM+DLOG((K+BRL)-1.)-DLOG(BRL)+DLOG(P)-DLOG(Q)
      SUM=SUM+DEXP(LNTERM)
      GOTO 100
C
  999 RETURN
      END
```

```
C
C     PROGRAM AVCAL.EMULATOR (the OSI/AVCAL emulator)
C
C     PROGRAM TO CALCULATE THE AVCAL - EMULATED METHODOLOGY
C          THE FOLLOWING PROGRAM WILL BE USED TO CALCULATE STOCKAGE
C     FOR THE CABAL STRUCTURES, IN SUCH A WAY AS TO EMULATE THE
C     NAVY AVCAL PROCESS.  THE DATA IS ASSUMED TO BE SORTED IN NIIN
C     SEQUENCE.
C
C          1.  INPUT DATA
C                SEVERAL TYPES OF RECORDS WILL BE READ INTO THE
C              PROGRAM.  THE FIRST RECORD TYPE (OF WHICH THERE WILL
C              BE ONLY ONE RECORD) DESCRIBES THE PROGRAM RUN TO
C              BE MADE AND GIVES SOME GLOBAL PARAMETERS.  IT
C              CONTAINS
C              SHIP FRTARG TA ECHO SLEV
C                  SHIP = SHIP OR SHORE STOCKAGE (1 = SHIP, 0 = SHORE)
C                FRTARG = FILL RATE TARGET FOR FILL RATE CALCULATION
C                    TA = ENDURANCE PERIOD TARGET FOR ATTRITION
C                         CALCULATIONS
C                  ECHO = 1 IF DATA ECHO IS DESIRED, 0 OTHERWISE
C                  SLEV = 1 IF SAFETY LEVEL ADDED, 0 OTHERWISE
C
C
C                THE SECOND RECORD TYPE DESCRIBES THE PLANNED FLYING
C              ACTIVITY OF THE VARIOUS AIRCRAFT TYPES.  IT IS REPEATED
C              AND EACH AIRCRAFT TYPE AND CONTAINS
C              TMSK    FHK    NAK
C                TMSK = NAME OF THE AIRCRAFT TYPE K
C                 FHK = FLYING HOURS PER AIRCRAFT PER DAY FOR AIRCRAFT
C                       TYPE K
C                 NAK = NUMBER OF AIRCRAFT OF THIS TYPE
C
C               RECORD TYPES 1 AND 2 ARE READ AS IN STREAM INPUT DATA.
```

```
C
C
C              THE THIRD RECORD TYPE CONTAINS COMPONENT DATA
C            USED FOR STOCKAGE CALCULATION AND COST BREAKDOWNS.
C            IT IS REPEATED FOR EACH COMPONENT (AND SEVERAL TIMES
C            FOR COMPONENTS WHICH HAVE MULTIPLE IOLS) AND LOOKS
C            AS FOLLOWS:
C            NIIN  IOL CCODE QPA PTYP C TS BCM MBAR DETREP
C            FOR A SINGLE COMPONENT TYPE (THAT IS FOR A NIIN) THE
C            ONLY DATA VARIATION BETWEEN RECORDS SHOULD BE THE IOL,
C            QPA, AND TMS.  THE DEFINITIONS OF TERMS ARE:
C               NIIN = NATIONAL ITEM IDENTIFICATION NUMBER FOR
C                      COMPONENT(NIIN(J),J=1,3)
C               IOL  = IOL THIS PART APPLIES TO
C               CCODE = COMPONENT CODE
C               QPA  = QUANTITY PER APPLICATION
C               PTYP = PART TYPE:  1 = WRA, 0 = SRA
C                  C = UNIT COST OF THE COMPONENT($)
C                 TS = SHIPBOARD TURN AROUND TIME
C                      (LOCAL, AI, AND REPAIR TIME IN DAYS)
C                BCM = FRACTION OF COMPONENTS DEMANDS BEYOND
C                      CAPABILITY OF MAINTENANCE AT THE SHIP
C               MBAR = DEMANDS PER FLYING HOUR
C             DPTREP = DEPOT REPAIR TIME (DAYS)
C
C             COMPONENT DATA ARE READ FROM UNIT FT08.
C
C
C         2.  GENERAL PROCESSING
C              THE FIRST STEP WILL BE TO READ ALL RECORDS OF TYPE
C            1 AND 2 AND STORE INTERNALLY.  THE REMAINING PROCESSING
C            WILL BE GENERALLY AS FOLLOWS:
C                 I.  READ ALL RECORDS OF TYPE 3 ASSOCIATED WITH A
C                     SINGLE NIIN AND STORE THE DATA INTERNALLY.
C                II.  COMPUTE THE TOTAL POOL QUANTITY, SR, FOR THE
```

```
C                         COMPONENT
C                  III.   COMPUTE THE TOTAL ATTRITION QUANTITY, SA, AND
C                         ADD TO THE POOL QUANTITY TO OBTAIN THE TOTAL
C                         AVCAL STOCK LEVEL
C                   IV.   UPDATE COUNTS OF COMPONENTS, STOCK, AND
C                         RERUNNING COST TOTALS
C                    V.   OUTPUT THE NIIN, STOCKAGE FOR THAT NIIN, AND
C                         COST OF STOCKAGE FOR THAT NIIN TO UNIT FT09
C                   VI.   GO TO STEP 1 UNLESS ALL COMPONENTS PROCESSED
C                         IN WHICH CASE OUTPUT ALL RUNNING TOTALS
C
C     DETAILED PROCESSING (PROGRAM)
      REAL TMS(10), FH(10), NA(10), TMSP(1000),
     *QPA(1000), MBAR, MBAR2, LAMSR, LAMSA,
     *CBD(10), STBD(10),CCODE(1000)
      REAL WRA/'W'/,SRA/'S'/,BAP/'B'/
      INTEGER IOL(1000),  SHIP, ECHO, IOL2,NIIN(3),NIIN2(3)
      INTEGER ECHO1,SHIP1,STND(6),SLEV,SLEV1
      INTEGER IOLDN(1000),PTYP,PTYP2
      INTEGER SSAM,SSATMP,SSAT,SSR,SSRTMP,SSA,END,CNT(10)
      DATA STND(2)/'STND'/,STND(1)/'ALTN'/,STND(3)/'SHOR'/
      DATA STND(4)/'SHIP'/,STND(5)/'NO'/,STND(6)/'YES'/
      DATA END/'END'/,AEND/'END'/
      DATA MXREC/20000/
C
C     READ INPUT DATA
C
      READ (5, 1000) SHIP, FRTARG, TA, ECHO, SLEV
 1000 FORMAT (I5, 2F10.2,2I5)
      WRITE(6,1011)
 1011 FORMAT(' ********AVCAL EMULATION OUTPUT*******')
      IF (ECHO.NE.1) GO TO 10
      WRITE(6,1012)
 1012 FORMAT(' SHP/SHR FILLTARG  ENDRPER  ECHO SAFETY LEV'/)
      SHIP1=STND(SHIP+3)
```

```
      ECHO1=STND(ECHO+5)
      SLEV1=STND(ECHO+5)
      WRITE (6, 1010) SHIP1,FRTARG, TA, ECHO1,SLEV1
 1010 FORMAT (1X, 1(1X,A4),2F10.2,4X,A4,4X,A4)
   10 CONTINUE
C
C     READ TMS TO BE CONSIDERED AND THE FLYING HOURS AND NUMBER OF
C     AIRCRAFT ON SHIP FOR EACH TMS
C
      DO 100 I=1, 10
      READ (5, 1020) TMS(I), FH(I), NA(I)
      IF (TMS(I).EQ.AEND) GO TO 20
      IF (ECHO.NE.1) GO TO 100
      IF(I.EQ.1)WRITE(6,1021)
 1021 FORMAT('         TMS       FH        NO')
      WRITE (6, 1030) TMS(I), FH(I), NA(I)
 1020 FORMAT (A4 ,6X, 2F10.2)
 1030 FORMAT (1X, A10, 2F10.2)
  100 CONTINUE
   20 CONTINUE
      KMAX = I-1
C
C     INITIALIZE COUNTING ARRAYS
C
      DO 5 I=1, 10
      CNT(I) = 0
      CBD(I) = 0
      STBD(I) = 0
    5 CONTINUE
      I = 1
      IREC=1
      IOLDN(1)=0
C
C     READ FIRST DATA RECORD
C
```

```
      READ(8,2040)TMSP(I),(NIIN(J),J=1,3),IOL(I),CCODE(I),QPA(I),PTYP,
     *C,TS,BCM,MBAR,DPTREP
      IF(NIIN(1).EQ.END)GO TO 950
      IF(ECHO.NE.1)GO TO 21
C
C     ECHO DATA IF REQUESTED AND IF THERE IS DEMAND(MBAR > 0)
C
      WRITE(6,1041)
 1041 FORMAT(/ '   NIIN      MBAR    BCM     TS     COST     PTYP ',
     *   'IOL    QPA    TMS   CC',/)
      IF(MBAR.NE.0)WRITE(6,1046)(NIIN(J),J=1,3),MBAR,BCM,TS,C,PTYP,
     *IOL(I),QPA(I),TMSP(I),CCODE(I)
   21 CONTINUE
C
C     READ SUBSEQUENT DATA RECORDS AND COMPARE WITH FIRST TO PICK UP
C     DIFFERENT COMPONENT CODES FOR SAME IOL NIIN, AND TMS
C
      DO 110 I = 2, 1000
      READ(8,2040,END=5000)TMSP2,(NIIN2(J),J=1,3),IOL2,CCODE2,QPA2,
     *PTYP2,C2,TS2,BCM2,MBAR2,DP2REP
 2040 FORMAT(A4,3A3,A4,A3,F4.0,I1,F9.2,F8.2,F6.4,F8.6,F8.2)
      IREC=IREC+1
      GO TO 251
 5000 CONTINUE
      NIIN2(1)=END
  251 CONTINUE
   22 CONTINUE
C
C     COMPARE FOR SAME NIIN.  IF NOT THE SAME DON'T ADD DEMAND
C
      DO 24 J=1,3
      IF (NIIN2(J).NE.NIIN(J)) GO TO 30
   24 CONTINUE
C
C     COMPARE FOR SAME IOL & TMS - IF NOT THE SAME DON'T ADD DEMAND
```

```
C
      IF(IOL2.NE.IOL(I-1).OR.TMSP2.NE.TMSP(I-1))GO TO 593
      IF(PTYP.EQ.PTYP2)GO TO 591
      BACKSPACE 6
C
C     IF PART TYPE IS NOT THE SAME SET PTYP TO HIGHEST LEVEL PART
C
      PTYP=MAX0(PTYP,PTYP2)
  593 CONTINUE
      IF(ECHO.NE.1)GO TO 591
      IF(MBAR2.NE.0)WRITE(6,1046)(NIIN2(J),J=1,3),MBAR2,BCM2,TS2,C2,
     *PTYP2,IOL2,QPA2,TMSP2,CCODE2
C
C     MOVE DATA FOR A COMPONENT THAT HAS SAME NIIN
C
  591 CONTINUE
      IOL(I) = IOL2
      QPA(I) = QPA2
      TMSP(I) = TMSP2
      CCODE(I)=CCODE2
      IOLDN(I)=0
  110 CONTINUE
   30 CONTINUE
C
C     SET NUMBER OF DEMAND RECORDS FOR COMPONENT WITH SAME NIIN
C
      LMAX = I-1
C
C     BEGIN PROCESSING FOR QUANTITIES
C
C     INITIALIZE VARIABLES
C
      COST = 0
      SSR = 0
      SSA = 0
```

```
      SSAT = 0
      SSAM = 0
      ILST = 1
      IDONE = 0
   40 CONTINUE
C
C ADD DEMANDS FOR TMS FOR THE SAME IOL AND NIIN
C
      D = 0
      DO 141 I=1,LMAX
      IF(IOLDN(I).EQ.0)GO TO 142
  141 CONTINUE
      GO TO 240
  142 ILST=I
      DO 140 I = ILST, LMAX
      IF (IOL(I).NE.IOL(ILST)) GO TO 140
      IOLDN(I)=1
      IF(I.EQ.ILST)GO TO 111
      IF(TMSP(I).EQ.TMSP(ILST))GO TO 140
  111 CONTINUE
      DO 150 K = 1, KMAX
      IF (TMS(K).NE.TMSP(I)) GO TO 150
      FHTMP = FH(K)
      NATMP = NA(K)
      GO TO 55
  150 CONTINUE
      GO TO 900
   55 CONTINUE
      D = D+MBAR*FHTMP*NATMP
  140 CONTINUE
      IF(ILST.EQ.LMAX)IDONE=1
   50 CONTINUE
C
C     DETERMINE ROTABLE POOL QUANTITY
C
```

```
      SSRTMP = 0
      LAMSA = D*BCM*TA
      LAMSR = (1. - BCM)*D*TS
C
C     IF SAFETY LEVEL STOCK IS REQUESTED ADD TO PIPELINE
C
C     IF (SLEV .EQ. 1) LAMSR = LAMSR + LAMSA
      IF(TS.EQ.0.)CNT(3)=CNT(3)+1
      IF(D.EQ.0.)CNT(4)=CNT(4)+1
      IF(C.EQ.0..OR.TS.EQ.0.OR.D.EQ.0.)CNT(2)=CNT(2)+1
      IF(PTYP.EQ.1)CNT(5)=CNT(5)+1
      IF(D.LE.0.)GO TO 964
C
C     ARRAY CNT:
C           CNT(1) = COUNT OF STOCKAGE RECORDS
C           CNT(2) = RECORDS WITH EITHER 0 UNIT COST,0 REPAIR TIME OR
C                    0 DEMAND
C           CNT(3) = RECORDS WITH 0 REPAIR TIME
C           CNT(4) = RECORDS WITH 0 DEMANDS/FH
C           CNT(5) = NUMBER OF WRA RECORDS
C           CNT(6) = COUNT OF NON ZERO STOCKAGE RECORDS
C           CNT(7) = COUNT OF WRA'S(PTYP=1)
C           CNT(8) = COUNT OF COMPONENTS WITH BCM=0
C           CNT(9) = COUNT OF NON-ZERO STOCKED ITEMS
C           CNT(10)= COUNT OF ROTABLE POOL STOCKED ITEMS
C
C     ARRAY CBD:
C           CBD(1) = TOTAL COST OF AVCAL
C           CBD(2) = TOTAL COST OF ROTABLE POOL
C           CBD(3) = TOTAL COST OF ATTRITION
C           CBD(4) = COST OF WRA STOCK(PTYP=1)
C           CBD(5) = ATTRITION STOCK COST
C           CBD(6) = ROTABLE POOL STOCK COST
C           CBD(7) = TOTAL COST
C
```

```
C     ARRAY STBD:
C           STBD(1) = RUNNING TOTAL OF STOCK
C           STBD(2) = COUNT OF COMPONENTS WITH BCM > 0
C           STBD(3) = COUNT OF COMPONENTS WITH ATTRITION STOCK
C           STBD(4) = COUNT OF COMPONENTS WITH COST > 100
C           STBD(5) = COUNT OF CONPONENTS WITH COST > 5000
C
C     SSA = ATTRITION STOCK
C     SSR = ROTABLE POOL STOCK
C     STOTAL = STOCK FOR THE COMPONENT(SSA + SSR)
C
      IF (LAMSR.LE.0) GO TO 60
      IF (LAMSR.GT..11) GO TO 65
      GO TO 60
   65 CONTINUE
      K=1
      EXPNT = EXP(-LAMSR)
      TERM = EXPNT*LAMSR
      SUMLST = EXPNT
      SUM = EXPNT*(1. + LAMSR)
C     WRITE(6,3010)D,LAMSR,EXPNT
 3010 FORMAT(1X,'D,LAMSR,EXPNT',3(1X,F10.4))
      DO 160 K = 2,500
C     WRITE(6,3000)SUM,SUMLST,TERM
 3000 FORMAT(1X,'SUM,SUMLST,TERM',3(1X,F10.4))
      IF (SUM.GE.FRTARG) GO TO 80
      SUMLST = SUM
      TERM = TERM*LAMSR/K
      SUM = SUM + TERM
  160 CONTINUE
   80 IF (.9-SUMLST.GE.SUM-.9) GO TO 90
      SSRTMP = K-1
      GO TO 95
   90 SSRTMP = K
   95 CONTINUE
```

```
      SSR = SSR + SSRTMP
C     WRITE(6,3020)SSR,SSRTMP
 3020 FORMAT(1X,'SSR,SSRTMP',2(1X,I5))
   60 CONTINUE
C
C     DETERMINE ATTRITION QUANTITY IF NO SAFETY LEVEL IS REQUESTED
C
      SSATMP=0
C     IF(SLEV .EQ. 1) GO TO 964
C     WRITE(6,3021)LAMSA
 3021 FORMAT(1X,'LAMSA',F10.4)
      IF (SSRTMP.GT.0 .AND. LAMSA.LT.1) GO TO 200
      IF (SSRTMP.EQ.0) GO TO 210
      SSATMP = IFIX(LAMSA+.5)
      GO TO 220
  210 CONTINUE
      IF (C.LT.5000.) GO TO 230
      IF (LAMSA.LT..5) GO TO 200
      SSATMP = IFIX(LAMSA+.5)
      GO TO 220
  230 CONTINUE
      IF (LAMSA.LT..34) GO TO 200
      SSATMP = IFIX(LAMSA+.5)
      IF(LAMSA.LT..5)SSATMP=1
  200 CONTINUE
  220 CONTINUE
      SSAT = SSATMP + SSAT
      SSAM = MAX0(SSAM, SSATMP)
C     WRITE(6,3022)SSAT,SSAM,SSATMP,C
 3022 FORMAT(1X,'SSAT,SSAM,SSATMP,C',3(1X,I5),1X,F10.4)
  964 CONTINUE
      CBD(7)=CBD(7)+C*(SSATMP+SSRTMP)
      CBD(5)=CBD(5)+C*SSATMP
      CBD(6)=CBD(6)+C*SSRTMP
      IF(BCM.GE.1.)GO TO 911
```

```
      CNT(8)=CNT(8)+1
      IF(SSATMP+SSRTMP.GT.0)CNT(9)=CNT(9)+1
      IF(SSRTMP.GT.0)CNT(10)=CNT(10)+1
      GO TO 912
  911 CONTINUE
      STBD(2)=STBD(2)+1
      IF(SSATMP.GT.0)STBD(3)=STBD(3)+1
      IF(C.GT.100.)STBD(4)=STBD(4)+1
      IF(C.GT.5000.)STBD(5)=STBD(5)+1
  912 CONTINUE
      IF (IDONE.EQ.1) GO TO 240
      ILST = I
      GO TO 40
  240 CONTINUE
      SSA = MAX0(SSAM, SSAT/2)
  900 CONTINUE
C
C     COMPUTE RUNNING TOTALS, ETC.
C     COST OF INDIVIDUAL STOCK
C
      COST = C*(SSA + SSR)
      CBD(1) = CBD(1) + COST
      CBD(2)=C*SSR+CBD(2)
      CBD(3)=C*SSA+CBD(3)
      IF(PTYP.EQ.1)CBD(4)=CBD(4)+COST
      CNT(1) = CNT(1) + 1
      IF(SSA+SSR.GT.0)CNT(6)=CNT(6)+1
      IF(PTYP.EQ.1)CNT(7)=CNT(7)+1
      STBD(1) = STBD(1) + SSA + SSR
      STOTAL = SSA + SSR
C     WRITE(6,3023)COST,CBD(1),CNT(1),STBD(1),STOTAL,SSA
 3023 FORMAT(1X,'COST,CBD(1),CNT(1),STBD(1),STOTAL,SSA',2(
     *1X,F10.0),1X,I5,2(1X,F10.0),1X,I5)
C
C     WRITE OUT STOCKAGE RECORDS
```

```
C
      WRITE (9, 1050) (NIIN(J),J=1,3), STOTAL
     *,SSA,SSR,COST
 1051 FORMAT(1X,3A3)
      IF(IREC.GT.MXREC)GO TO 950
      IF (NIIN2(1).EQ.END) GO TO 950
      DO 26 J=1,3
   26 NIIN(J) = NIIN2(J)
      MBAR = MBAR2
      BCM = BCM2
      TS = TS2
      C = C2
      PTYP = PTYP2
      IOL(1) = IOL2
      QPA(1) = QPA2
      TMSP(1) = TMSP2
      CCODE(1)=CCODE2
      IOLDN(1)=0
      IF(ECHO.NE.1)GO TO 21
C
C     ECHO DATA IF REQUESTED AND IF THERE IS DEMAND(MBAR > 0)
C
      IF(MBAR.NE.0)WRITE(6,1046)(NIIN(I),I=1,3),MBAR,BCM,TS,C,PTYP,
     *IOL(1),QPA(1),TMSP(1),CCODE(1)
      GO TO 21
C
C     THIS IS THE END OF DATA RECORDS
C
  950 CONTINUE
C     WRITE OUT RUNNING TOTALS
      WRITE(6,1063)
      WRITE (6, 1060) (CBD(I), I = 1, 10)
      WRITE(6,1064)
      WRITE (6, 1061) (CNT(I), I = 1, 10)
      WRITE(6,1065)
```

AD-A160 848 ENHANCING INTEGRATION AND RESPONSIVENESS IN NAVAL AVIATION LOGISTICS: SPARES STOCKAGE ISSUES(U) RAND CORP SANTA MONICA CA J B ABELL ET AL. JAN 85 2/2

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END

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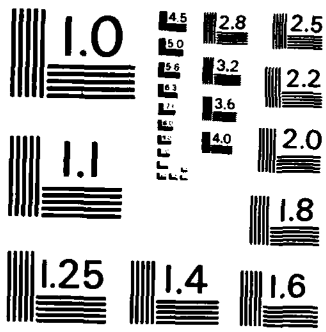

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

```
      WRITE (6, 1062) (STBD(I), I = 1, 10)
 1067 FORMAT(1X,I5,2(1X,F10.1))
 1063 FORMAT(' **TOTAL COST BREAKDOWNS**')
 1064 FORMAT(' **COUNT BREAKDOWNS**')
 1065 FORMAT(' **STOCK BREAKDOWNS**')
 1066 FORMAT(' ITERATIONS COST-DELTA  TAMOD')
 1040 FORMAT(1X,3A3,15X,F7.6,1X,F5.4,11X,F5.2,1X,F9.2,1X,I1,
     *1X,I1,1X,A4,1X,F6.0,1X,A4,1X,A3)
 1046 FORMAT(1X,3A3,1X,F7.6,1X,F5.3,1X,F5.2,1X,F9.2,2X,
     *1X,I1,1X,A4,1X,F6.0,1X,A4,1X,A3)
 1050 FORMAT (1X, 3A3, 1X, F10.0,2(1X,I5),1X,F10.0)
 1060 FORMAT (1X, 10 (F9.0, 1X))
 1061 FORMAT (1X, 10 (I6, 1X))
 1062 FORMAT (1X, 10 (F6.0, 1X))
      STOP
      END
```

Appendix B

VARIANCE-TO-MEAN RATIOS

The VTMR of component pipeline quantities is often used as a measure of uncertainty. Under the classical assumption of Poisson-distributed demands, the VTMR for each component is equal to one; however, several empirical studies suggest that in most cases of interest, the VTMR exceeds one.

Our efforts to obtain historical VTMR values for the sample of 552 F-14 components used in this demonstration were frustrated by an apparently irreconcilable problem in the data file (drawn from the Navy's Selected Item Extract Generator). We found VTMRs ranging from below zero (impossible) to over two million (highly implausible). Rather than basing our comparison of computational methods upon such suspect numbers, we turned to the use of an estimation technique proposed by Sherbrooke [13] in which the VTMR for component i takes the form

$$\mathrm{VTMR} = 1 + a m_i^{\,b}$$

Here, m_i denotes the mean pipeline size for component i, and a and b are values that depend upon the components in question. For recoverable components managed by the Air Force Logistics Command, Sherbrooke found a and b to be given by

$$a = 0.141 + 0.0125Q,$$
$$\text{and } b = 0.583 - 0.0045Q,$$

where Q denotes a forecasting period, in quarters. There is no compelling reason to suppose that these values hold in any universal sense; on the other hand, they seem reasonable. In this spirit, we arbitrarily selected a forecasting period of 10 quarters (a typical component procurement lead time) and rounded a and b to values of 0.25 and 0.5, respectively. In addition, we appended a third term to the expression for VTMR to account for components that are ordered in quantities greater than one. Thus, we have

$$VTMR = 1 + 0.25m_i^{0.5} + OQ_i^2/12m_i$$

where OQ_i is the order quantity for component i. Finally, we specified an upper bound of 25.0 on all computed VTMRs; this, however, turned out to be of almost no consequence, as only two components were affected.

Appendix C

THE WEAPON SYSTEM AVAILABILITY METRIC

The use of weapon system availability both as the objective function and as the criterion of evaluation in the computation and comparison of stockage postures offers a number of advantages not found in the use of more traditional measures, such as supply materiel availability (SMA), or fill rate. Perhaps the most appealing of these is the focus on particular weapon systems rather than on inventory system performance. The availability of a weapon system is far more relevant in an operational sense than is SMA. In addition, it is possible to account for varying levels of weapon system complexity, so that, to some extent, the capability of the entire force can be kept in proper balance.

Weapon system availability may be defined as the probability that an aircraft selected at random is found to have no component shortages. If we assume that shortages of different components occur independently of one another, we may express weapon system availability, A, as

$$A = \prod_{i=1}^{N} q_i,$$

where N is the number of different components comprised by the weapon system and q_i denotes the probability that an aircraft selected at random has no shortage of component i. If we assume further that no effort is made in the direction of cannibalization, but instead, that shortages are distributed at random across all aircraft, we may estimate the probability of shortage for a particular installation of component i, p_i, as

$$p_i = EBO_i/TI_i$$

where EBO_i is the expected number of backorders for component i across all aircraft and TI_i is the total number of installations of component i across all aircraft. We may write q_i in terms of p_i:

$$q_i = (1 - AF_i) + AF_i(1 - p_i)^{QPA_i}$$

where AF_i denotes the application fraction, or proportion of aircraft of a particular type that contain component i, and QPA_i denotes the quantity per aircraft of component i. We then have, as a final expression for weapon system availability,

$$A = \prod_{i=1}^{N} [(1 - AF_i) + AF_i(1 - EBO_i/TI_i)^{QPA_i}]$$

This formulation follows closely the approach taken in the LMI Aircraft Availability Model, and is consistent with other well-known models, including Dyna-METRIC [10,8]. It should be pointed out, however, that for purposes of the demonstration discussed in this Note, no attempt was made to treat such features as levels of indenture and common components. While these are unquestionably important in everyday applications, we felt that they would needlessly complicate the illustration of the efficacy of the weapon system availability method. The interested reader is referred to the LMI paper for a more complete exposition of enhancements to the basic expression.

A frequent criticism of availability-oriented, marginal-analytic approaches to stockage computation is that they often suggest very heavy expenditures for relatively cheap components and a correspondingly light investment in expensive components. In practice, however, it is often the expensive components that are the most critical to aircraft mission performance. Therefore, such stockage strategies may be self-defeating in a sense.

This problem may be circumvented to a large extent by quantifying the mission essentiality of each component. The quantification of mission essentiality depends on more than simply the quantification of the importance of a component to the operation of a system or subsystem. It also involves failure mode analysis and the determination of the relationship between failures, component removals, and component demands. The Navy is now in the process of assigning essentiality codes to aircraft components. It is an important step in moving toward more realistic stockage postures.

Given a realistic determination of component essentiality, the problem of taking explicit account of it in stockage computations is simple and straightforward. If we let s_i, the essentiality of component i, vary from 0.0 (nonessential) to 1.0 (absolutely essential), we may use it as a weight for the expected backorder term. Thus, we may write the essentiality-weighted weapon system availability, A', simply as

$$A' = \prod_{i=1}^{N} [(1 - AF_i) + AF_i(1 - s_i EBO_i/TI_i)^{QPA_i}]$$

Appendix D

AVIATION SUPPLY OFFICE SHORTAGE COSTS

Simply defined, the shortage cost of a weapon system component is the degradation in operational capability, quantified in terms of dollars, attributable to its absence. Shortage costs figure prominently in the current method of wholesale stockage computation employed by the Navy's Aviation Supply Office. Although from the definition above it may seem that they are measurable in some empirical fashion, shortage costs are in reality employed primarily as control parameters in the generation and assessment of alternative inventory policies. Using CARES, ASO can compare the effects of varying shortage costs on the basis of such performance criteria as mean delay time and SMA, or fill rate. The values that appear to furnish the best results can then be used in Levels and Strat to compute stock levels and budget projections.

Ideally, shortage cost would be a component-specific quantity. This would at the very least be impractical, however, in the context of ASO's present strategy of comparing different sets of values and selecting the best one. Clearly, the large number of components in the Navy's inventory system would preclude any sort of comprehensive evaluation. Therefore, ASO aggregates shortage costs by four-digit cognizance code. The values established for the September 30, 1983, Strat run are given below in Table D.1; also included are the limits on stockout risk that were used in the same computation [14]. Both the shortage costs and the limits on stockout risk were incorporated into our emulation of ASO's computation of wholesale stock levels.

Table D.1

ASO'S SHORTAGE COSTS AND RISK LIMITS
30 SEP 83 STRAT

COG	RISK MAX	RISK MIN	SHORTAGE COST ($)
1R GA,TA,MA,FA,RA, NA,LA,FE,GE,AZ, DZ,JZ,KZ,WZ,NZ, PZ,QZ,TZ,ZZ,TX, DX,EX,FX,MX,UX	.40	.01	25,000
BP,FP,EP	.40	.01	20,000
AY,MF	.40	.01	35,000
CY,SZ,PF	.40	.01	45,000
1R CS	.40	.01	23,000
VX	.35	.01	130,000
GZ,LZ,RZ	.40	.01	13,000
1R balance	.40	.01	15,000
2R/8R GZ,LZ,RZ,GA, TA,MA,AV,BA,BE, BH,EC,EE,EF,EV, FC,FE,GE,GT,KA, LA,LC,MC,NC,CY, SZ,PF,AY,MF	.40	.05	140,000
AZ,DZ,JZ,KZ,WZ, NZ,PZ,QZ,TZ,ZZ, TX,UX,DX,EX,FX, MX	.40	.05	147,000
FA,RA,NA	.40	.05	90,000
CS,BP,EP,FP	.40	.05	999,000
2R/8R balance	.40	.05	372,000
4R all	.40	.05	145,500
5R all	.40	.01	200,000
8N all	.40	.05	140,000

Appendix E

COMPARISON OF STOCKAGE POSTURES

Among the several stockage computation techniques discussed in this Note, two are of primary interest: the emulated Navy method and the availability-balanced, multi-echelon method. A comparison of the equal-cost stockage postures produced by these methods reveals a number of rather startling differences in both range and depth; these are summarized in Section III.

Table E.1 contains a detailed breakdown by component of each posture, with stock levels given both for the wholesale echelon and for each of two types of retail locations (Naval Air Stations and aircraft carriers). In addition, component replacement cost is listed to illustrate more clearly the tradeoffs between high- and low-cost components made by the multi-echelon algorithm. It should be noted that the retail stock levels presented in Table E.1 correspond to the allowance for just a single site; in the actual computation, however, we provided for two air stations and four carriers.

Table E.1

"NAVY" AND BALANCED MULTI-ECHELON STOCKAGE POSTURES

		STOCK LEVELS					
		WHOLESALE		N.A.S.		CARRIER	
COMPONENT	COST	"NAVY"	M.E.	"NAVY"	M.E.	"NAVY"	M.E.
1	25.00	81	67	12	30	11	28
2	9180.00	0	0	0	2	0	1
3	23560.00	0	0	0	0	0	1
4	253420.00	1	1	0	0	0	0
5	5151.00	6	9	0	2	0	3
6	601.00	0	0	0	3	0	2
7	3303.00	6	5	2	5	0	2
8	3460.00	27	32	3	8	3	8
9	3700.00	17	19	2	6	1	6
10	15995.00	12	11	5	7	3	5
11	1807.18	20	28	1	7	2	8
12	685.00	2	2	0	12	0	9
13	2666.52	2	2	0	3	0	3
14	3146.00	3	4	1	4	1	4
15	18200.00	18	24	1	3	1	3
16	703.00	5	7	0	3	0	4
17	884.00	3	4	0	3	0	2
18	3100.00	38	37	5	10	5	11
19	769.29	1	1	0	3	0	2
20	1446.15	3	5	0	3	0	2
21	23.00	0	0	0	5	0	6
22	779.41	0	0	0	3	0	3
23	1267.00	5	7	0	3	0	3
24	5000.00	38	47	4	9	5	10
25	1960.00	10	14	1	4	0	3
26	1662.74	3	4	0	3	0	3
27	1742.30	2	4	0	2	0	3
28	1580.80	9	12	1	4	1	5
29	5300.00	11	12	1	5	0	2
30	1432.60	2	5	0	2	0	3
31	3888.00	4	3	2	4	0	3
32	500.00	0	0	0	4	0	2
33	6195.62	4	5	0	2	0	3
34	5086.60	2	2	2	4	1	3
35	1400.80	6	5	1	4	0	3
36	2698.60	2	4	0	1	0	2
37	6160.00	0	1	2	3	1	4
38	1520.00	0	0	0	2	0	2
39	4230.17	5	5	1	2	0	1
40	592.50	31	29	2	10	2	9
41	591.37	302	391	8	34	6	31

Table E.1 (continued)

		STOCK LEVELS					
		WHOLESALE		N.A.S.		CARRIER	
COMPONENT	COST	"NAVY"	M.E.	"NAVY"	M.E.	"NAVY"	M.E.
42	2804.00	56	66	4	13	2	10
43	6293.00	7	8	3	7	3	5
44	6592.00	76	64	14	17	21	20
45	7156.36	4	5	0	2	0	1
46	75151.09	15	13	2	2	0	1
47	3200.72	6	8	0	2	0	2
48	6000.00	2	2	0	2	0	3
49	13740.00	0	1	2	2	0	1
50	3064.54	0	0	2	4	1	4
51	1707.74	11	16	0	4	0	3
52	1490.95	1	1	2	4	0	4
53	6427.66	1	1	2	3	0	3
54	5005.00	2	4	0	1	0	1
55	2724.00	1	2	0	3	0	1
56	3578.00	0	1	0	2	0	2
57	9560.90	5	9	0	2	1	3
58	416.91	0	0	0	3	0	3
59	4427.85	0	0	0	2	0	3
60	9078.00	11	14	1	4	1	4
61	10108.68	0	0	2	3	0	2
62	5293.39	20	16	3	7	2	6
63	19640.00	37	47	3	6	5	8
64	28084.34	3	3	0	1	0	2
65	680.09	26	24	3	11	2	9
66	25448.03	14	14	2	3	1	3
67	9585.60	14	17	2	4	0	3
68	1055.67	3	3	0	3	0	3
69	212034.00	118	93	23	11	23	11
70	51397.00	3	3	5	7	3	3
71	63713.00	19	14	9	9	5	6
72	21830.00	0	0	0	0	0	0
73	45327.00	0	1	2	2	1	2
74	70583.00	9	7	6	6	3	4
75	55805.00	3	3	1	1	0	0
76	145817.00	9	7	7	7	5	4
77	15007.00	3	3	2	3	1	3
78	564.53	0	0	0	3	0	3
79	93640.00	8	4	10	10	4	4
80	58945.00	4	3	4	4	2	3
81	88080.00	23	22	3	3	3	3
82	13675.00	438	713	9	27	22	36
83	2489.49	0	0	0	3	0	1
84	1550.00	3	3	1	6	0	5
85	1860.00	112	118	11	22	13	23
86	75000.00	8	11	4	4	5	4
87	697.10	185	227	4	25	4	24

Table E.1 (continued)

		STOCK LEVELS					
		WHOLESALE		N.A.S.		CARRIER	
COMPONENT	COST	"NAVY"	M.E.	"NAVY"	M.E.	"NAVY"	M.E.
88	4382.00	3	4	2	5	3	5
89	1381.97	127	158	4	18	5	19
90	4700.00	62	79	7	14	9	15
91	6375.00	4	4	2	4	1	4
92	7892.00	2	2	2	3	1	3
93	5078.89	2	6	0	1	0	1
94	10672.49	33	40	3	7	2	5
95	7765.00	3	3	2	5	1	3
96	3993.26	4	5	0	2	0	2
97	22308.00	10	10	3	3	1	3
98	12641.00	0	0	0	1	0	1
99	1222.00	0	1	0	3	0	3
100	3300.00	7	10	1	3	0	2
101	12390.00	10	16	1	3	1	4
102	1850.00	0	0	0	2	0	2
103	88849.00	9	5	11	12	4	5
104	6120.00	2	3	0	2	1	3
105	51270.38	2	3	0	0	0	0
106	45708.40	2	3	0	1	0	0
107	2442.41	0	0	0	3	0	2
108	5164.92	1	1	0	2	0	2
109	1182.00	0	0	0	2	0	3
110	1359.77	0	0	0	3	0	3
111	12828.98	0	1	0	1	0	1
112	22424.06	0	1	0	0	0	1
113	9597.17	0	0	0	2	0	1
114	18625.79	1	1	0	1	0	0
115	11625.00	2	5	0	1	0	1
116	5363.23	4	4	0	2	0	1
117	2616.80	0	1	0	2	0	1
118	4367.00	4	5	1	2	0	1
119	6768.00	2	4	0	1	0	1
120	2108.00	2	4	0	1	0	2
121	1056.42	2	3	0	2	0	1
122	5568.37	1	3	0	1	0	0
123	11130.33	15	23	1	3	0	2
124	9361.14	27	44	1	4	1	4
125	38834.47	4	7	0	0	0	0
126	693.00	10	8	3	8	4	8
127	21568.00	0	1	0	1	0	0
128	586.63	0	0	0	3	0	3
129	1359.77	0	0	0	2	0	2
130	8650.00	2	2	0	3	0	2
131	4200.00	7	9	2	5	1	4
132	4048.00	0	0	0	2	0	2
133	1304.24	0	0	0	2	0	2

Table E.1 (continued)

		STOCK LEVELS					
		WHOLESALE		N.A.S.		CARRIER	
COMPONENT	COST	"NAVY"	M.E.	"NAVY"	M.E.	"NAVY"	M.E.
134	8678.00	3	4	1	3	1	3
135	9432.00	3	5	2	3	1	4
136	6919.00	2	4	1	2	1	3
137	6702.00	0	2	2	3	1	3
138	25143.00	1	3	0	0	0	0
139	2875.00	0	0	0	2	0	3
140	32116.54	0	1	0	1	0	0
141	77500.00	3	2	3	2	2	2
142	6900.00	3	3	0	2	0	1
143	5250.00	2	1	0	3	0	3
144	4485.00	16	14	5	10	2	5
145	15730.00	5	7	2	3	1	3
146	47270.00	0	0	0	0	0	0
147	637.20	0	0	0	3	0	2
148	640.93	3	3	1	5	0	3
149	351.00	2	2	1	5	0	4
150	1342.68	14	13	1	6	1	6
151	4695.00	8	7	3	6	2	5
152	817.95	0	0	0	3	0	3
153	804.00	23	17	3	9	4	10
154	1931.00	21	35	0	4	1	5
155	701.99	0	0	0	3	0	3
156	470.86	0	0	0	3	0	3
157	3140.42	1	1	0	2	0	1
158	4586.78	1	1	0	1	0	1
159	4928.18	17	30	0	3	0	3
160	647.88	0	0	0	3	0	3
161	3085.83	0	0	0	2	0	2
162	4458.65	0	2	0	1	1	3
163	2499.19	1	1	0	2	0	1
164	1115.62	0	0	0	2	0	3
165	550.00	0	1	0	3	0	3
166	2082.59	0	0	0	1	0	1
167	5050.00	3	5	0	2	0	2
168	3074.19	9	15	1	4	1	5
169	1484.56	0	0	0	2	0	2
170	27344.00	3	6	0	0	0	0
171	24232.00	2	6	0	0	0	0
172	28496.00	65	52	11	11	10	10
173	1933.00	4	4	1	4	0	3
174	2960.00	2	2	2	4	1	3
175	5825.00	5	4	2	5	1	3
176	793.68	0	0	0	2	0	3
177	5564.00	11	10	5	9	5	8
178	8561.32	133	164	14	21	16	21
179	131.29	28	36	1	11	0	12

Table E.1 (continued)

COMPONENT	COST	STOCK LEVELS WHOLESALE "NAVY"	M.E.	N.A.S. "NAVY"	M.E.	CARRIER "NAVY"	M.E.
180	5080.00	1	1	0	2	0	2
181	7500.00	0	0	0	2	0	1
182	13500.00	2	3	2	2	1	3
183	4842.00	12	11	2	5	2	5
184	807.17	0	1	0	2	0	2
185	1531.05	0	0	0	2	0	3
186	1022.60	9	6	1	5	1	4
187	2761.34	9	10	3	5	1	5
188	1599.87	199	249	10	34	5	24
189	3578.91	105	88	16	22	19	22
190	870.00	11	16	2	6	4	10
191	843.86	1	2	0	4	0	4
192	12840.00	3	3	3	5	2	4
193	639.00	19	17	4	9	2	8
194	4446.08	0	1	0	1	0	1
195	7640.00	10	10	3	5	3	5
196	11750.00	3	4	0	2	0	1
197	2612.97	5	5	1	3	0	2
198	3917.00	10	11	1	4	1	5
199	10630.00	9	10	3	6	3	5
200	6380.00	0	0	0	1	0	2
201	1902.02	101	73	24	41	26	38
202	5378.00	1	2	0	2	0	1
203	578.56	2	2	0	4	0	2
204	1781.72	0	0	0	2	0	2
205	5230.00	3	3	0	2	0	2
206	2115.18	0	0	0	2	0	2
207	28632.00	15	13	5	6	5	5
208	126.36	0	1	0	4	0	3
209	16357.31	2	6	0	0	0	1
210	27443.72	3	5	0	1	0	0
211	268.40	12	11	1	7	1	6
212	8279.68	10	9	5	7	3	5
213	899.00	28	19	5	11	5	11
214	648.00	13	10	2	7	2	7
215	602.70	41	32	5	14	6	14
216	2458.00	0	0	0	3	0	2
217	962.00	3	5	0	5	0	5
218	2032.52	2	3	0	2	0	2
219	1568.77	1	2	2	4	0	4
220	23100.00	0	1	0	1	0	2
221	23779.00	10	12	1	3	1	3
222	25500.00	5	7	1	2	1	2
223	897.19	22	28	1	7	1	7
224	1635.00	0	0	0	3	0	3
225	13100.00	4	5	1	3	1	3

Table E.1 (continued)

		STOCK LEVELS					
		WHOLESALE		N.A.S.		CARRIER	
COMPONENT	COST	"NAVY"	M.E.	"NAVY"	M.E.	"NAVY"	M.E.
226	2531.61	0	1	0	2	0	2
227	603.00	2	1	0	4	0	3
228	5388.70	6	10	2	5	1	5
229	8651.00	1	2	0	2	0	1
230	1330.00	28	36	1	8	2	9
231	1200.00	3	3	1	3	0	2
232	8532.28	42	46	5	14	6	16
233	5403.05	2	4	0	1	0	1
234	2700.00	7	12	0	3	1	4
235	3045.00	2	5	0	1	0	1
236	1394.87	7	7	1	4	1	4
237	2298.76	5	7	0	3	1	3
238	4112.63	13	24	0	3	1	4
239	9310.00	0	0	0	2	0	1
240	6384.00	1	4	0	0	0	1
241	32391.57	10	17	0	1	0	2
242	41179.65	11	20	0	1	0	1
243	3714.00	16	26	1	4	1	5
244	1500.00	0	0	0	2	0	2
245	3104.00	4	6	0	2	0	3
246	4100.00	0	0	0	1	0	1
247	2087.60	1	2	0	2	0	3
248	2827.06	16	14	2	7	0	4
249	796.00	21	19	2	8	2	8
250	5154.19	3	4	0	2	0	1
251	1060.33	7	10	1	4	1	5
252	1091.76	2	2	0	3	0	3
253	1553.29	34	32	4	10	3	10
254	163000.00	50	48	9	5	10	6
255	17971.00	8	13	0	1	0	1
256	9800.00	9	13	2	4	1	4
257	4709.00	2	3	2	4	1	4
258	7946.34	2	4	0	1	0	1
259	1329.00	3	5	0	2	0	3
260	11665.23	0	0	0	0	0	2
261	10742.00	2	2	2	3	0	2
262	3480.76	2	4	0	2	0	1
263	3448.00	11	14	1	4	1	5
264	2155.25	0	0	0	3	0	3
265	1282.79	4	5	1	4	1	4
266	3986.45	5	5	3	6	2	5
267	107260.00	0	0	0	0	0	0
268	1650.00	0	1	0	2	0	3
269	3462.70	3	7	0	2	0	2
270	671.40	2	3	0	4	1	4
271	115561.00	4	3	3	2	2	1

Table E.1 (continued)

		STOCK LEVELS					
		WHOLESALE		N.A.S.		CARRIER	
COMPONENT	COST	"NAVY"	M.E.	"NAVY"	M.E.	"NAVY"	M.E.
272	2027.14	7	7	1	4	1	4
273	1830.00	15	15	2	7	1	5
274	3358.00	0	0	0	2	0	3
275	6405.66	1	3	0	1	0	1
276	1295.00	8	7	1	5	0	3
277	1471.52	3	7	0	2	0	3
278	16608.94	4	4	1	2	0	2
279	7486.72	3	4	2	2	1	3
280	13803.18	0	1	1	2	0	2
281	29322.66	0	0	0	0	0	1
282	1781.85	0	0	0	2	0	3
283	4977.27	19	18	3	7	1	5
284	9040.00	7	8	2	4	0	3
285	3479.25	8	7	1	4	1	4
286	1700.00	5	7	0	3	1	4
287	1126.05	2	5	0	2	0	1
288	2309.61	9	12	1	4	0	2
289	3459.00	1	2	1	3	0	3
290	7000.00	6	10	3	5	3	5
291	3500.00	3	3	3	6	2	4
292	782.50	6	7	1	5	1	5
293	565.00	0	1	0	3	0	3
294	1149.40	31	35	4	11	4	10
295	3677.52	0	0	0	2	0	1
296	6090.64	6	9	0	14	0	12
297	7588.00	13	21	3	6	2	5
298	728.00	2	4	0	3	0	4
299	4881.00	8	6	3	6	1	4
300	9423.00	8	9	2	5	2	5
301	4169.00	41	87	6	40	3	38
302	19837.34	7	13	0	1	0	1
303	18723.40	10	15	0	2	0	1
304	1280.00	8	9	2	5	5	9
305	813.00	1	1	0	4	0	2
306	8125.68	0	1	0	1	0	2
307	1547.28	0	0	0	2	0	2
308	11276.50	15	18	3	5	1	4
309	1670.00	1	1	0	3	0	2
310	15578.00	2	2	1	2	0	1
311	16706.00	14	16	2	3	1	3
312	3340.00	0	0	0	2	0	1
313	6550.00	0	1	0	1	0	1
314	3201.45	3	3	2	5	1	4
315	4454.56	35	58	4	8	6	12
316	42129.00	75	63	13	12	13	11
317	19800.00	35	54	5	8	8	10

Table E.1 (continued)

COMPONENT	COST	STOCK LEVELS WHOLESALE "NAVY"	WHOLESALE M.E.	N.A.S. "NAVY"	N.A.S. M.E.	CARRIER "NAVY"	CARRIER M.E.
318	24800.00	54	70	3	7	3	7
319	1030.71	3	5	0	3	0	2
320	66980.00	66	53	16	15	7	7
321	2277.00	0	0	0	1	0	3
322	24389.00	15	24	2	4	3	5
323	3875.00	11	10	2	5	2	5
324	3065.00	5	4	1	3	0	2
325	755.00	50	53	4	14	3	14
326	1953.00	10	12	1	5	1	6
327	849.22	1	2	0	2	0	1
328	2842.46	1	1	0	2	0	1
329	4924.64	1	1	0	2	0	1
330	8050.00	1	1	0	1	0	0
331	9252.36	1	1	0	1	0	0
332	3700.00	1	2	0	1	0	1
333	8230.24	3	8	0	1	0	2
334	7190.47	3	4	0	2	0	2
335	3320.32	8	8	1	5	0	3
336	2781.00	5	5	3	8	2	6
337	7829.54	6	10	0	2	0	2
338	6462.00	3	4	2	5	2	5
339	6518.00	8	11	2	6	3	6
340	15221.00	4	6	2	3	2	4
341	29150.00	12	10	6	7	4	5
342	3896.50	3	3	3	6	2	5
343	3521.94	2	3	0	2	0	1
344	6010.00	0	0	0	2	0	1
345	2360.00	1	1	0	4	0	4
346	715.74	6	8	0	4	0	4
347	2670.00	1	2	0	2	0	5
348	9589.80	90	102	7	14	2	8
349	40856.00	2	2	0	1	0	1
350	2597.00	8	13	1	4	1	5
351	2283.50	11	17	1	5	1	5
352	264.00	15	11	1	13	1	14
353	793.10	0	1	0	3	0	4
354	1010.00	0	0	0	3	0	2
355	3612.40	15	13	3	6	2	6
356	2317.49	3	3	1	3	0	3
357	2565.72	0	1	0	1	0	2
358	4532.00	1	1	0	2	0	1
359	2255.00	2	3	2	4	2	5
360	1990.00	42	33	7	13	7	12
361	3617.01	182	222	5	20	2	13
362	3414.05	737	881	28	62	13	37
363	3590.68	219	271	6	22	2	15

Table E.1 (continued)

		STOCK LEVELS					
		WHOLESALE		N.A.S.		CARRIER	
COMPONENT	COST	"NAVY"	M.E.	"NAVY"	M.E.	"NAVY"	M.E.
364	5990.00	105	91	17	21	15	18
365	19000.00	8	9	4	7	3	6
366	5729.23	2	2	0	2	0	2
367	151869.77	11	8	2	1	0	0
368	8888.79	0	1	0	2	0	1
369	5836.56	0	0	0	2	0	1
370	6589.58	2	5	2	2	1	3
371	9125.60	2	4	2	6	0	9
372	7022.99	9	15	3	7	3	6
373	64619.00	30	28	4	4	5	5
374	10307.86	0	0	0	2	0	1
375	3702.85	0	1	0	0	0	2
376	7670.00	0	1	2	4	1	3
377	1968.00	3	4	1	4	0	3
378	12915.81	82	102	5	11	3	8
379	12915.81	70	83	6	11	1	6
380	20305.75	9	16	1	2	1	2
381	10557.04	0	0	0	1	0	0
382	176296.18	4	3	1	0	0	0
383	11529.38	11	12	3	4	2	5
384	10435.49	10	10	2	4	2	5
385	5000.00	15	14	2	6	2	5
386	7640.00	7	6	1	3	1	4
387	28250.00	11	11	6	8	4	6
388	765.00	0	1	2	5	1	4
389	22190.00	0	1	0	1	0	1
390	29053.34	1	1	0	1	0	1
391	2071.54	0	0	0	3	0	2
392	3027.00	245	308	15	37	8	23
393	19278.17	7	8	1	2	0	2
394	472.93	0	0	0	2	0	4
395	62034.00	8	6	6	8	3	4
396	77385.00	4	6	0	0	1	2
397	34437.61	13	13	1	2	1	2
398	34485.71	7	10	1	1	0	2
399	24712.13	8	13	0	2	0	2
400	210244.98	4	4	2	0	1	0
401	2430.00	0	1	0	1	0	1
402	4473.15	0	0	2	4	0	2
403	57116.00	75	57	21	22	7	9
404	7573.00	10	9	2	4	1	4
405	2510.00	0	0	0	2	0	2
406	10153.61	0	1	0	1	0	1
407	61780.00	19	14	10	11	4	6
408	3522.13	595	753	28	58	16	38
409	24860.00	0	0	0	0	0	0

Table E.1 (continued)

		STOCK LEVELS					
		WHOLESALE		N.A.S.		CARRIER	
COMPONENT	COST	"NAVY"	M.E.	"NAVY"	M.E.	"NAVY"	M.E.
410	24860.00	0	0	0	1	0	1
411	6374.68	0	0	0	2	0	3
412	2414.95	3	3	2	4	1	4
413	10568.00	4	12	0	0	1	4
414	9310.75	45	58	3	8	2	7
415	11226.94	3	4	0	2	0	1
416	70367.17	3	4	3	2	2	2
417	14258.07	0	0	0	1	0	0
418	13231.00	15	17	3	5	1	3
419	91304.00	23	20	7	7	3	4
420	11358.18	3	3	2	3	1	3
421	6464.94	1	2	0	1	0	1
422	5383.40	4	6	0	2	0	2
423	6175.25	0	1	0	2	0	2
424	9740.00	15	14	6	10	3	6
425	11531.00	3	4	3	5	2	4
426	41932.90	40	53	1	4	0	2
427	4088.00	3	4	0	2	0	1
428	1469.22	0	1	0	3	0	1
429	19447.16	8	12	1	2	2	4
430	10064.09	7	8	2	5	1	3
431	9059.64	7	11	1	3	2	5
432	3280.00	0	0	0	2	0	2
433	1742.20	9	10	1	5	1	5
434	684.07	7	8	1	5	1	6
435	8518.00	1	2	0	1	0	0
436	3037.89	17	24	0	3	0	2
437	874.00	3	3	0	3	0	3
438	17661.25	0	0	0	1	0	1
439	26316.00	0	0	0	0	0	1
440	52592.75	0	0	0	0	0	0
441	33660.00	12	10	6	8	5	6
442	4104.91	274	442	8	26	12	30
443	170295.43	2	2	0	0	0	0
444	170295.43	1	2	0	0	0	0
445	27483.93	0	0	0	1	0	0
446	12250.00	2	2	0	2	0	2
447	27712.67	0	0	0	1	0	0
448	21910.00	0	0	0	1	0	0
449	17851.67	0	0	0	1	0	0
450	31079.00	0	1	0	1	0	0
451	20409.23	0	0	0	1	0	0
452	20754.48	0	0	0	1	0	0
453	4500.00	2	3	0	2	0	2
454	1745.28	9	10	1	4	1	5
455	1688.23	33	38	3	9	2	8

Table E.1 (continued)

		STOCK LEVELS					
		WHOLESALE		N.A.S.		CARRIER	
COMPONENT	COST	"NAVY"	M.E.	"NAVY"	M.E.	"NAVY"	M.E.
456	1373.00	24	21	3	9	2	8
457	8728.95	0	1	0	1	0	1
458	8738.54	0	1	0	1	0	2
459	8120.47	1	1	0	2	0	2
460	8113.27	0	0	0	2	0	1
461	13647.00	0	1	0	1	0	0
462	9341.56	1	2	0	1	0	1
463	1681.35	7	10	1	4	1	5
464	9657.00	16	15	2	5	2	5
465	3700.00	0	0	0	2	0	1
466	8179.41	0	0	0	2	0	2
467	20667.00	227	192	36	33	20	20
468	19189.00	5	8	0	1	0	1
469	3719.00	5	6	3	6	2	5
470	46590.00	6	5	3	4	3	4
471	47890.28	2	2	0	1	0	1
472	13625.90	2	2	0	1	0	1
473	48782.56	2	2	1	1	0	1
474	4427.95	27	35	2	9	2	9
475	1498.50	1	1	0	3	0	2
476	9038.83	14	14	2	5	1	4
477	2775.00	55	57	6	14	4	11
478	936.50	18	16	3	10	2	11
479	3200.00	9	14	2	6	2	6
480	168800.00	17	14	10	8	7	5
481	21316.30	12	11	6	7	3	5
482	59703.00	2	3	3	2	2	2
483	31190.00	3	3	2	3	2	3
484	123949.00	15	18	11	10	9	8
485	5100.00	0	0	0	1	0	2
486	4317.00	7	9	1	3	1	4
487	13918.00	25	20	4	7	1	4
488	2971.00	0	0	0	2	0	2
489	3085.00	39	37	7	12	5	11
490	7150.00	0	0	0	1	0	2
491	51117.00	9	8	4	5	2	3
492	8969.00	30	31	6	9	5	8
493	21000.00	0	0	0	0	0	0
494	21000.00	0	1	1	1	0	2
495	14693.23	33	41	5	7	6	9
496	47000.00	26	22	4	4	4	4
497	8840.00	108	100	20	28	10	16
498	12000.00	2	2	2	3	1	3
499	45000.00	0	0	0	0	0	0
500	7660.00	2	3	0	1	0	0
501	47000.00	24	20	4	4	3	4

Table E.1 (continued)

COMPONENT	COST	STOCK LEVELS — WHOLESALE "NAVY"	WHOLESALE M.E.	N.A.S. "NAVY"	N.A.S. M.E.	CARRIER "NAVY"	CARRIER M.E.
502	14995.00	2	2	0	2	1	2
503	26384.00	6	6	3	5	2	4
504	4008.18	0	0	0	1	0	2
505	17695.00	2	2	0	1	0	1
506	139647.61	22	41	3	2	3	4
507	22763.00	4	6	2	2	1	3
508	35000.00	20	20	3	4	2	4
509	23850.00	0	0	0	0	0	0
510	23850.00	0	0	0	1	0	1
511	23850.00	0	1	2	2	0	2
512	23850.00	0	0	0	1	0	1
513	23850.00	0	0	0	1	0	2
514	21651.80	8	6	4	6	3	5
515	880.00	0	0	1	4	0	4
516	7209.67	0	0	0	1	0	1
517	17135.34	6	7	3	4	2	4
518	15521.00	26	27	6	9	4	7
519	4500.00	46	58	7	15	5	11
520	6290.00	9	11	2	4	1	4
521	8676.27	49	43	8	11	7	10
522	28000.00	0	0	1	1	0	1
523	6565.00	122	114	19	23	19	21
524	160000.00	0	0	0	0	0	0
525	1014.90	0	0	0	2	0	3
526	1546.42	0	0	0	3	0	2
527	150000.00	0	0	0	0	0	0
528	9820.00	27	27	4	7	3	6
529	2246.04	0	0	0	3	0	2
530	64932.83	8	6	3	3	2	2
531	36039.10	33	37	3	5	3	4
532	219494.00	20	13	8	4	5	3
533	31450.00	9	12	1	2	1	3
534	375000.00	39	27	18	2	10	6
535	201400.00	15	10	2	1	0	0
536	87500.00	13	9	9	8	3	4
537	45000.00	6	7	3	4	3	3
538	55750.00	3	3	0	1	0	0
539	9680.00	24	41	1	3	0	3
540	8371.53	21	37	0	3	0	3
541	37000.00	0	0	0	1	0	1
542	15000.00	2	2	0	2	0	1
543	37000.00	2	2	1	2	0	1
544	37000.00	0	1	0	1	0	1
545	43787.00	37	47	2	4	2	4
546	62050.00	27	28	5	5	4	4
547	62050.00	35	30	7	7	4	4

Table E.1 (continued)

		STOCK LEVELS					
		WHOLESALE		N.A.S.		CARRIER	
COMPONENT	COST	"NAVY"	M.E.	"NAVY"	M.E.	"NAVY"	M.E.
548	1319.00	59	50	8	16	9	16
549	43870.00	98	88	14	13	13	11
550	136568.00	9	6	5	4	2	2
551	14037.00	0	0	2	3	1	2
552	30400.00	0	0	0	1	0	1

Appendix F

DATA ON VARIANCE-TO-MEAN RATIOS

We include here some additional observations of component removals by month and location as well as the corresponding removal *rates* adjusted for flying hours. The data from which these observations were drawn were kindly provided by the Navy Ships Parts Control Center. They cover the 28-month period from August 1981 through November 1983, and include action-taken codes P and R (remove; remove and replace) coupled with how-malfunctioned codes other than 799 through 811. The time period was specified so as to cover two consecutive deployments of each of two aircraft carriers, the U.S.S. Nimitz and the U.S.S. Eisenhower. The Nimitz was deployed from August 1981 through January 1982 and from November 1982 through April 1983. The Eisenhower was deployed from January through June 1982 and from May through November 1983.

Table F.1 shows the unadjusted component removals aggregated monthly. Table F.2 reflects the component removal rates adjusted for flying hours.

Table F.1

UNADJUSTED REMOVALS AGGREGATED MONTHLY

	Oceana		Miramar		Nimitz 1		Nimitz 2		Eisenhower 1		Eisenhower 2	
WUC	Mean	VTMR	Mean	VTMR	Mean	VTMR	Mean	VTMR	Mean	VTMR	Mean	VTMR
56X21	32.8	10.9	38.9	3.2	21.5	3.0	17.8	6.9	27.2	3.3	20.9	1.1
56X23	0.0		0.0		0.0		0.0		0.0		0.1	1.0
56X25	22.9	7.3	20.1	2.6	9.5	1.6	3.7	3.1	6.7	1.1	6.9	1.1
56X44	1.6	45.0	4.1	11.9	0.0		0.0		0.0		0.1	1.0
69163	3.8	3.0	6.3	2.1	2.2	1.0	0.5	0.6	0.3	0.8	5.6	1.8
69182	17.5	6.7	19.2	3.8	5.0	2.3	3.8	2.2	6.7	0.7	11.9	2.0
713C1	9.8	3.9	9.9	7.1	3.7	2.9	3.3	2.4	4.5	3.2	3.4	1.6
734H1	23.6	2.8	24.6	2.5	10.7	2.2	7.8	4.0	9.3	0.5	9.4	2.2
74A1C	33.0	8.5	29.9	4.1	8.0	3.0	7.8	2.2	11.3	1.9	6.4	1.4
74A1G	19.4	3.2	22.6	3.6	8.0	3.4	4.8	2.8	6.2	1.0	6.0	2.0
74A1J	5.9	3.3	5.2	1.4	1.3	0.5	2.2	3.6	1.5	1.3	0.3	0.8
74A1Q	56.5	6.6	43.1	4.6	17.5	4.4	15.2	9.0	12.7	0.5	21.4	0.7
74A1U	23.2	5.9	17.6	3.8	7.8	5.3	7.3	3.1	6.3	0.9	5.3	2.3
74A1V	25.0	4.5	20.9	14.8	9.8	2.8	9.7	6.9	10.7	3.4	9.9	3.8
74A1Z	0.2	1.1	0.1	0.9	0.0		0.0		0.0		0.0	
74A11	22.4	5.4	23.7	3.7	9.2	1.0	7.2	7.3	6.7	0.8	6.7	0.6
74A15	25.6	6.8	26.2	2.2	7.8	3.8	5.8	3.8	9.5	2.9	13.3	0.8
74A4E	26.0	5.6	21.5	1.2	11.0	2.2	7.0	3.5	11.5	1.2	11.1	2.9
74A45	12.4	5.7	12.2	17.4	5.7	1.4	3.3	3.6	5.8	2.7	3.7	1.4
74A48	15.2	4.2	13.8	1.6	9.2	6.1	5.3	2.5	13.5	2.2	9.3	1.0
74A5M	28.0	4.9	27.8	9.4	15.0	1.8	5.2	3.4	13.7	1.9	11.7	2.0
74A55	13.2	1.9	12.7	2.9	7.7	3.5	2.3	0.3	6.3	0.8	5.4	0.9
74A74	8.1	2.1	8.3	3.3	2.7	0.7	2.5	3.3	3.3	0.6	2.0	1.3
74A75	4.2	5.1	4.9	2.2	2.8	1.8	4.0	0.8	2.5	2.0	2.1	0.4
74A78	.07	1.0	0.1	1.0	0.0		0.0		0.0		0.0	
763W1	1.0	1.5	3.8	2.2	2.0	2.4	1.3	1.4	1.5	1.3	3.6	1.8
76731	1.3	4.8	11.3	13.8	1.2	2.2	0.5	1.4	1.2	0.8	0.0	

Table F.2

REMOVALS PER 1000 FLYING HOURS AGGREGATED MONTHLY

	Oceana		Miramar		Nimitz 1		Nimitz 2		Eisenhower 1		Eisenhower 2	
WUC	Mean	VTMR	Mean	VTMR	Mean	VTMR	Mean	VTMR	Mean	VTMR	Mean	VTMR
56X21	17.8	7.2	20.8	0.8	24.7	2.5	26.9	2.2	36.6	2.1	25.4	0.8
56X23	0.0		0.0		0.0		0.0		0.0		0.2	1.0
56X25	12.4	4.3	10.8	2.8	10.9	1.0	5.5	2.4	9.0	1.9	8.3	0.9
56X44	0.9	33.4	2.2	12.4	0.0		0.0		0.0		0.2	0.7
69163	2.0	1.5	3.4	2.2	2.5	0.5	0.8	0.8	0.4	1.0	6.8	1.6
69182	9.5	3.5	10.3	5.0	5.8	3.2	5.8	2.3	9.0	2.0	14.4	1.6
713C1	5.3	1.9	5.3	4.5	4.2	1.3	5.0	1.7	6.1	2.4	4.2	1.3
734H1	12.8	1.3	13.2	3.4	12.3	0.2	11.9	2.3	12.6	2.1	11.5	2.5
74A1C	18.0	3.5	16.0	4.3	9.2	1.3	11.8	0.9	15.3	2.1	7.8	2.0
74A1G	10.5	2.0	12.1	3.3	9.2	3.5	7.3	1.0	8.3	0.3	7.3	1.6
74A1J	3.2	2.0	2.8	1.1	1.5	0.4	3.3	1.9	2.0	1.0	0.3	0.8
74A1Q	30.7	3.5	23.0	4.8	20.1	1.2	22.9	4.0	17.1	1.6	26.1	0.5
74A1U	12.6	2.9	9.4	3.9	9.0	3.1	11.1	1.3	8.5	1.1	6.4	2.6
74A1V	13.6	2.2	11.2	17.8	11.3	0.9	14.6	3.7	14.4	2.8	12.0	5.7
74A1Z	0.1	1.4	.05	1.0	0.0		0.0		0.0		0.0	
74A11	12.2	3.6	12.7	4.3	10.5	3.3	10.8	4.0	9.0	0.6	8.2	1.3
74A15	13.9	4.5	14.0	2.3	9.0	1.4	8.8	1.6	12.8	1.3	16.2	0.8
74A4E	14.1	3.7	11.5	1.8	12.7	1.0	10.6	1.6	15.5	1.4	13.6	1.6
74A45	6.7	3.4	6.5	22.7	6.5	0.2	5.0	1.8	7.9	2.4	4.5	1.0
74A48	8.2	2.5	7.4	1.6	10.5	3.5	8.0	1.4	18.2	0.5	11.3	0.6
74A5M	15.2	3.2	14.9	10.4	17.3	1.4	7.8	1.4	18.4	3.0	14.3	1.1
74A55	7.2	1.9	6.8	2.5	8.8	1.4	3.5	0.2	8.5	0.7	6.6	0.9
74A74	4.4	1.3	4.4	3.6	3.1	0.3	3.8	4.7	4.5	1.2	2.4	1.2
74A75	2.3	3.1	2.6	2.5	3.3	2.8	6.0	0.3	3.4	2.2	2.6	0.6
74A78	.04	0.8	.04	0.8	0.0		0.0		0.0		0.0	
763W1	0.5	1.1	2.0	2.4	2.3	1.4	2.0	1.4	2.0	1.5	4.3	1.0
76731	0.7	3.5	6.1	9.4	1.3	1.8	0.8	1.7	1.6	0.8		

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